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# Journal of the Council for Scientific and Industrial Research.

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## The Use of Borax for the Prevention of Fly Breeding in Trap Baits

*By D. F. Waterhouse, M.Sc.,* and Mary E. Fuller, B.Sc.†*

*Summary.*

Many flies may be produced by untreated baits in blowfly traps, the number bred sometimes exceeding the total number of flies caught by the trap. The flies bred are generally Calliphoras or, less frequently, *Chrysomyia rufifacies*. No *Lucilia cuprina* were produced. Borax (2 per cent. or more by weight), sprinkled over the surface, inhibited larval development, but generally reduced the attractiveness of the bait to all species. *L. cuprina* was sometimes an exception to this statement. The effect of trapping on the fly population is considered and the conclusion is reached that the addition of borax to baits is not warranted.

### 1. Introduction.

Observations in the field and experience in experimental trapping have shown that larvae from captured flies develop freely in the bait chambers of traps and escape to produce a new generation of flies. M. E. Fuller had early appreciated this fact and had undertaken a number of experiments with borax and other substances to prevent larval development in the baits. Her observations were uncompleted at the time of her death and at a later stage D. F. Waterhouse repeated and extended them, arriving at somewhat different conclusions from those to which the earlier work pointed. In the present paper both sets of work are brought together, but the interpretation of them is solely the responsibility of D. F. Waterhouse.

The work on bait treatment previously reported (Freney, 1932A and B, 1937; Fuller, 1934A) aimed primarily at enhancing attractiveness, prevention of maggot development being a minor consideration. This paper records the results of bait treatment to prevent larval growth and the effect of such treatment on the attractiveness of the bait.

The Western Australian trap (Newman and Clark, 1941) which is the best type available for field use, allows free access of flies to the bait and also unhampered escape of prepupae through the entrance

* An officer of the Division of Economic Entomology.

† The late Miss Fuller was an officer of the Division of Economic Entomology at the time her part of the work described was carried out.

slits. Many modifications have been tested, but no simple and efficient trap with mechanical means of preventing the flies from ovipositing or the maggots from escaping has yet been devised. Gravid female flies will readily deposit eggs or larvae in a trap, and any device which allows the escape of attractive carrion odours whilst preventing access of the flies to the bait, greatly increases the complexity and therefore the cost of the trap. It will be shown in this paper that the number of maggots escaping from a trap is often large and, under some conditions, may exceed the number of flies captured.

## 2. Method.

The experiments were carried out at Canberra, A.C.T., in Western Australian traps and in small, standardized, glass traps built on the Western Australian principle; these were used on the Nicholson turntable (Freney, 1937). The results were then checked in Western Australian traps set under normal field conditions. The traps were placed in shallow, sand-filled, maggot-proof containers to retain the maggots escaping from the baits. Only those species which are important to the sheep blowfly problem or cause domestic annoyance were included in the figures considered in this paper. These are the primary* species *Lucilia cuprina* Wied., *L. sericata* Meig., *Calliphora stygia* Fabr., and *C. augur* Fabr., and the secondary fly *Chrysomyia rufifacies* Macq. Particular attention was paid to *L. cuprina* which is responsible for most of the strikes occurring on sheep.

## 3. Results.

(i) *A comparison of the number of flies caught and the number of flies produced by a bait.*

Many factors have been found to influence the number of maggots escaping from a trap and developing into adults. The more important of these were:—

(*a*) The amount of bait.

(*b*) The type of bait.

(*c*) The competition of the larvae for food, and the weather conditions influencing severity of competition. For instance, of 35 untreated baits in glass traps (Table 1), seven produced no flies owing to the effects of competition, and two dried up before any flies were caught.

(*d*) The presence of predators and parasites which concentrate around traps and greatly reduce the number of flies bred. The beetles, *Saprinus* (Histeridae) and *Creophilus* (Staphylinidae), and also ants seize the maggots as they emerge from the traps, and in experiments of this kind the predators have an unusual advantage in that the maggots, being confined to the outer containers, have little chance to escape them. However, by collecting the maggots daily in some experiments a fairly true estimate was obtained of the number which would probably escape and develop under field conditions. Five, at least, of the above-mentioned 35 baits showed evidence that most of the maggots escaping from the bait pans had been destroyed by predators, and the

* Primary flies are able to initiate strikes on sheep, while the secondaries follow later.

few survivors were attacked by parasites, so that a very small number of flies was produced. The number of flies bred from all the other baits was also considerably reduced by the depredations of parasites or predators, the activity of these being largely influenced by weather conditions.

Summing up, of the 35 untreated baits exposed in glass traps between November and March (Table 1), 7 produced no flies from the bait owing to competition, 2 dried up before any flies were caught, 5 had almost all the maggots or puparia destroyed by predators and parasites, and the remaining 21 produced numbers of flies. Of these 21 traps, 13 produced more flies than they caught, and 1 produced as many. Although 8,096 flies were caught, the total population difference produced by the 35 traps was the destruction of 1,467 flies. A total of 158 *L. cuprina* was caught in the traps. (an average of 4·5 per trap), while none were recorded as having bred in the baits.

TABLE 1.—COMPARISON BETWEEN THE NUMBER OF FLIES PRODUCED BY THE BAIT AND THE NUMBER CAUGHT—GLASS TRAPS.

| Month Exposed. | Number of Flies. | | Effect of Trapping on Fly Population. | Bait. |
|---|---|---|---|---|
| | Caught. | Bred. | + Increase − Decrease. | |
| November to December .. .. | 310 | 384 | + 74 | Rat |
| | 223 | 180 | − 43 | |
| November to December .. .. | 443 | 201 | −242 | Cat |
| | 280 | 499 | +219 | |
| December .. .. .. | 194 | 194 | 0 | Rat |
| | 109 | 185 | + 76 | |
| | 253 | 145 | −108 | |
| | 54 | 201 | +147 | |
| December .. .. .. | 125 | 1 | −124 | Mouse |
| | 105 | 0 | −105 | |
| | 149 | 0 | −149 | |
| | 95 | 0 | − 95 | |
| December .. .. .. | 259 | 0 | −259 | Rat |
| | 625 | 5 | −620 | |
| December .. .. .. | 136 | 0 | −136 | Mouse |
| December .. .. .. | 337 | 0 | −337 | Rat |
| December .. .. .. | 0 | 0 | 0 | Lambs' tails |
| | 0 | 0 | 0 | |
| January to February .. .. | 60 | 714 | +654 | Rat |
| | 217 | 402 | +185 | |
| | 105 | 137 | + 32 | |
| January to February .. .. | 219 | 78 | −141 | Liver |
| | 208 | 333 | +125 | |
| | 233 | 339 | +106 | |
| | 231 | 728 | +497 | |
| January to February .. .. | 495 | 580 | + 85 | Liver |
| | 320 | 668 | +348 | |
| January to February .. | 122 | 331 | +209 | Rat |
| February .. .. .. | 356 | 0 | −356 | Liver |
| | 271 | 29 | −242 | |
| February .. .. .. | 43 | 4 | − 39 | Rat |
| March .. .. .. .. | 227 | 86 | −141 | Rat |
| | 475 | 19 | −456 | |
| March to April .. .. .. | 448 | 103 | −345 | Rat |
| | 369 | 83 | −286 | |

The figures for Western Australian traps were somewhat different (Table 2). Of 17 baits, two small animals (less than 300 g. in weight) suffered complete and rapid desiccation and produced no flies, three were flooded by rain and all the maggots drowned, and the remaining twelve bred flies in varying numbers. Two bred more than half the number caught and two bred more than they caught. These latter two were guinea pig carcasses which are relatively unattractive, and hence were not overcrowded with maggots. The 17 baits bred 13,118 flies and caught 102,255. Of this total, 1,941 were *L. cuprina*, an average of 11¼ per trap.

TABLE 2.—COMPARISON BETWEEN THE NUMBER OF FLIES PRODUCED BY THE BAIT AND THE NUMBER CAUGHT—WESTERN AUSTRALIAN TRAPS.

| Month Exposed. | Number of Flies. | | Effect of Trapping on Fly Population. | Bait. |
|---|---|---|---|---|
| | Caught. | Bred. | + Increase − Decrease. | |
| October to November .. .. | 10,557 | 4,450 | − 6,107 | Cat |
| November .. .. .. | 7,143 | 850 | − 6,293 | Cat |
| November to December .. .. | 2,833 | Larvae | − 2,833 | Cat |
| | 1,013 | drowned | − 1,013 | |
| December .. .. .. | 1,958 | 1,500 | − 458 | Cat |
| December .. .. .. | 3,949 | 370 | − 3,579 | Cat |
| December .. .. .. | 580 | Larvae | − 580 | Dog |
| | 313 | dessicated | − 313 | |
| December to January .. .. | 5,327 | Larvae drowned | − 5,327 | Guinea pig |
| January to February .. .. | 186 | 380 | + 194 | Guinea |
| | 803 | 944 | + 141 | pig |
| January to February .. .. | 6,335 | 660 | − 5,675 | Liver |
| | 27,299 | 966 | −26,333 | |
| January to February .. .. | 15,433 | 500 | −14,933 | Liver |
| February .. .. .. | 1,488 | 839 | − 649 | Cat |
| March to April .. .. .. | 13,043 | 503 | −12,540 | Liver |
| | 3,995 | 1,156 | − 2,839 | |

The majority of the maggots recorded as escaping from baits in Tables 1 and 2 were *Calliphora augur* while *C. stygia* was occasionally found. When *Ch. rufifacies* was present in the bait, most of the maggots of this species pupated on the bait or in the bait pan, and the resulting flies were trapped immediately on emergence. Occasionally, however, larvae did escape. No *Lucilia* were recorded at any time from the bait.

(ii) *Prevention of Maggot Development.*

In view of the fact that trap baits frequently produced flies, experiments were set up to determine whether breeding could be prevented without lowering the attractiveness of the bait.

Various preliminary experiments and general field observations had demonstrated that, although arsenicals prevent larval development, they so greatly reduce the attractiveness of baits to all flies, and particularly to primary flies, that their use can readily be excluded on this ground. Experimental work had shown that both borax and boric acid were effective maggot poisons, whether dusted on carcasses

(Fuller, unpublished) or incorporated in dressings for struck sheep (Freney *et al.*, 1936; Lennox, 1940, 1941). There is, however, no published information on the attractiveness of borax-treated baits to flies. One of the great advantages of these boron compounds is their low toxicity to mammals, so that they can be handled with perfect safety. Since borax is cheaper than boric acid, extensive tests were conducted with this compound. During five months' trapping, 44 tests were made of the effect of borax on maggot development in both carcass and liver baits (Table 3). The borax was sprinkled on to the surface of the bait, the amount used varying from 2 to 10 per cent. by weight. Some of these baits were left dry and to others water was added but, in every case, the treatment was completely effective in preventing flies from being produced, and the few larvae which developed to full size died before pupating.

Table 3.—The Effect of Bait Treatments on Fly Catches and Number of Flies Produced by the Bait—Glass Traps.

| Number of Tests. | Treatment. | Average Number Flies Bred per Trap. | Average Number Flies Caught per Trap. |
|---|---|---|---|
| 44 | Borax .. .. .. .. .. | 0 | 257 |
| 7 | $Na_2S$ + borax .. .. .. .. | 0 | 516 |
| 7 | $Na_2S$ .. .. .. .. .. | 123 | 680 |
| 7 | Nicotine sulphate .. .. .. .. | 40 | 118 |
| 35 | Controls .. .. .. .. .. | 179 | 231 |

In the same series of experiments, tests were made of the effect of adding sodium sulphide, a mixture of borax and sodium sulphide, or nicotine sulphate to the bait. Sodium sulphide (2·5 to 5 per cent.) treatment of baits did not prevent maggot development, but it reduced the number of maggots escaping. This was probably due to the more intense competition for food as the bait was more attractive.

A mixture of sodium sulphide and borax in equal quantities (2·5 per cent. of each) prevented adults being produced in all but one instance, when a few *Helicobia* (Sarcophagidae) were bred. Nicotine sulphate in concentrations from 2 to 8 per cent. often prevented adults being produced, although larvae generally began to develop on the baits. None of the baits produced *L. cuprina*.

(iii) *The Attractiveness of Borax-treated Baits.*

Since borax had proved efficient in preventing larval development it was next tested for its effect on bait attractiveness.

(*a*) *Glass traps.*—Considering first of all the results with 91 baits in glass traps (Table 4), borax-treated baits caught more flies than the controls, but this difference was not significant. The figures for primary and secondary flies, and for *L. cuprina*, were also examined. The presence of borax did not influence the catch of primary flies or of *L. cuprina*, but it resulted in a significantly higher catch of the secondary fly *Ch. rufifacies*.

TABLE 4.—THE EFFECT OF BORAX ON THE ATTRACTIVENESS OF BAITS IN GLASS TRAPS.

| Number of Traps in Experiment. | Concentration of Borax in Treated Bait (Percentage by Weight). | Average Number of Flies per Trap. | | | |
|---|---|---|---|---|---|
| | | Borax. | | Control. | |
| | | Total. | *Lucilia cuprina.* | Total. | *Lucilia cuprina.* |
| 6 | 2 | 161 | 1·3 | 127 | 0·3 |
| 10 | 2½ | 75 | 6·4 | 174 | 21·4 |
| 4 | 3 | 193 | 4·5 | 136 | 9·0 |
| 35 | 5 | 467 | 5·7 | 240 | 2·6 |
| 12 | 7 | 338 | 11·7 | 198 | 6·3 |
| 20 | 8 | 241 | 5·8 | 246 | 7·4 |
| 4 | 10 | 313 | 4·0 | 403 | 13·0 |

Early work by Freney (1932A, B, 1937) and Fuller (1934A) demonstrated that the addition of sodium sulphide usually rendered baits much more attractive than untreated ones. Now sodium sulphide alone has been shown to be an ineffective maggot poison (Table 3), but when borax was added the mixture prevented larval development. Borax was used at 5 per cent. concentration, sulphide at 2½ per cent., and borax + sulphide at 2½ per cent. each. An analysis of seven comparisons which are summarized in Table 5 showed that borax did not have any significant effect upon the attractiveness either of liver or liver plus sodium sulphide baits. In these tests, borax treated baits caught slightly fewer primary flies and about the same number of secondaries as the controls. The presence of sodium sulphide enhanced the attractiveness of the bait whether borax was present or not.

TABLE 5.—THE EFFECT OF BAIT TREATMENT ON BLOWFLY CATCHES—GLASS TRAPS.

| — | Borax + $Na_2S$. | $Na_2S$. | Borax. | Control. |
|---|---|---|---|---|
| Catch per trap .. .. .. | 516 | 683 | 222 | 266 |
| Percentage of primaries in catch .. | 67 | 69 | 75 | 88 |
| *L. cuprina* per trap .. .. | 2 | 6 | 3 | 4 |

(*b*) *Western Australian Traps.*—While borax sprinkled on the baits of Western Australian traps was invariably successful in preventing maggot development, it considerably reduced the total number of flies caught (Table 6), the borax-treated baits catching only about half as many flies as the controls. These experiments were conducted over two seasons and involved more than 300,000 flies, so doubtless they give a truer picture of what occurs under field conditions than the experiments with glass traps. It is important to note, however, in these

experiments there was no difference in the number of *L. cuprina* caught and there was also some indication that the borax-treated bait caught a higher proportion of primary flies than the control bait.

TABLE 6.—THE EFFECT OF BAIT TREATMENT ON THE ATTRACTIVENESS OF BAITS IN WESTERN AUSTRALIAN TRAPS.

| Experiment. | Borax. | | | | Control. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of Traps. | Average Flies per Trap. | | Percentage Primaries. | Number of Traps. | Average Flies per Trap. | | Percentage Primaries. |
| | | Total. | *Lucilia cuprina.* | | | Total. | *Lucilia cuprina.* | |
| W.A. traps in the field | 23 | 3,101 | 152 | 55 | 17 | 6,051 | 114 | 44 |
| W.A. traps on turn tables .. .. | 11 | 3,286 | 200 | 68 | 11 | 7,103 | 224 | 54 |
| Average .. .. | .. | 3,194 | 176 | 62 | .. | 6,577 | 169 | 49 |

A comparison was also made of the relative effects of borax on wet and on dry baits (Table 7). For the wet baits water was added until about half of the bait was submerged.

TABLE 7.—THE EFFECT ON WESTERN AUSTRALIAN TRAP CATCHES OF THE ADDITION OF WATER TO THE BAIT.

| Bait. | Untreated. | | | | Borax. | | | |
|---|---|---|---|---|---|---|---|---|
| | Wet. | | Dry. | | Wet. | | Dry. | |
| | Total Flies. | *Lucilia cuprina.* | Total Flies. | *Lucilia cuprina.* | Total Flies. | *Lucilia cuprina.* | Total Flies. | *Lucilia cuprina.* |
| Dog .. .. | 580 | 35 | 313 | 5 | 629 | 17 | 513 | 12 |
| Guinea pig .. | 803 | 5 | 186 | 0 | 115 | 2 | 321 | 1 |
| Liver .. .. | 40,342 | 365 | 10,330 | 226 | 14,056 | 431 | 1,414 | 49 |
| Totals .. .. | 41,725 | 405 | 10,829 | 231 | 14,800 | 450 | 2,248 | 62 |

It is clear from these few experiments that wet baits were more attractive than dry ones and also that the reduction in numbers of flies caught when borax was added was, if anything, less for wet than for dry baits. The enhancing effect of adding water is most noticeable under dry conditions when moistened baits remain attractive longer than dry baits, and therefore catch more flies; under humid conditions there is often little difference between wet and dry baits. Although there was little difference in the number of *L. cuprina* caught by control and treated wet baits, the number caught by the borax-treated dry bait was much smaller than the number caught by the untreated bait.

The effect of addition of sodium sulphide to control and to borax-treated baits was also investigated (Table 8). Although the addition of 2½ per cent. sodium sulphide enhanced the attractiveness of both baits, the improvement was more noticeable for the bait without the borax. In these experiments, the presence of borax resulted in a distinct lowering of the numbers of flies caught. The number of *L. cuprina* caught was also much lower, although the percentages of this species attracted to the various baits did not vary greatly.

TABLE 8.—THE EFFECT OF BAIT TREATMENT ON BLOWFLY CATCHES—WESTERN AUSTRALIAN TRAPS.

| — | Borax + $Na_2S$. | $Na_2S$. | Borax. | Control. |
|---|---|---|---|---|
| Catch per trap .. .. .. | 725 | 5,616 | 544 | 3,234 |
| Percentage of primaries in catch .. | 88 | 65 | 88 | 83 |
| *L. cuprina* per trap .. .. | 63 | 416 | 54 | 297 |

## 4. Discussion.

Prevention of fly breeding in trap baits may be considered from two points of view, namely, the effect of such prevention on the population of sheep blowflies, and its effect on the blowflies causing annoyance in houses.

The action of borax in slowing down bacterial decomposition might have been expected to favour a high proportion of primary sheep flies in the total catch, since these species are more attracted to fresh baits than other species. While the bulk of the evidence indicates that a higher proportion of primary flies (including *L. cuprina*) was caught by borax-treated baits than by non-borax baits, the actual numbers caught were generally less. However, the figures are too variable to generalize satisfactorily. Of the primary flies, *L. cuprina* is responsible for many more strikes than any other (Mackerras and Fuller, 1937). Although it was present in almost all the catches, and must often have deposited eggs on the untreated baits, no adults were produced. This is not unexpected, for Fuller (1934B) and Waterhouse (1946) have shown that *L. cuprina* is produced infrequently and in small numbers from carrion. Failure of the eggs laid on the baits to survive is principally due to intense competition for food in the larval stage, other species crowding *Lucilia* out. There is, therefore, no advantage in adding borax to the bait, so far as this species is concerned.

The three species *C. stygia, C. augur,* and *Ch. rufifacies,* which are of some importance as sheep blowflies, are also the main blowflies causing domestic annoyance. All three species breed in the baits, but most *Ch. rufifacies* adults are trapped on emergence since the larvae generally pupate in the bait pan

Unpoisoned baits give the greater catches, but this benefit is likely to be offset in the next generation by production of adults from larvae that escape, which will result in a temporary local increase in population density. Further, if trapping is carried out intensively and on

a large scale, the population decrease will result in a general population increase in the next generation caused by the reduced competition among larvae for food (Fuller, 1934B). As an immediate reduction is generally required, there seems to be no object in adding borax to baits. It can also be concluded that the most promising line of future investigation would be directed towards increasing bait attractiveness.

The factors underlying the very great variability in results from trap to trap and day to day during these experiments have not been elucidated, but it is considered that such variation would necessarily occur in the field, so that any results presented in this paper are valid for practical purposes. The reasons for the difference in results in glass traps and in the Western Australian trap also remain undetermined.

## 5. Acknowledgments.

Thanks are due to Mr G. A. McIntyre for statistical analyses of the results.

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# A Case of House Infestation by a Tree-Dwelling Colony of *Coptotermes frenchi* Hill.

*By F. J. Gay, B.Sc., D.I.C.**

*Summary.*

An account is given of damage to a house caused by *Coptotermes frenchi*. Part of the subterranean gallery system of the colony was traced out and the nest located in a recently dead tree about 70 feet from the house. The depth at which the galleries were found indicates that soil treatments outside building walls may frequently be of no value.

White arsenic applied to runways within the building is considered to have been responsible for the observed heavy mortality in the colony.

## 1. Introduction.

In March, 1946, a request was received by the Division of Economic Entomology for advice on combating an infestation of termites in a station homestead near Canberra, A.C.T. Preliminary inspection showed that the termite responsible was *Coptotermes frenchi* Hill, and that the infestation was confined to a recently added section of the house. This section, constructed of concrete bricks, was added in 1937, and no precautions were taken against the possible ingress of termites. Damage was most severe in a single room, a bedroom, in which the architrave of the door had been attacked extensively and the floor had sagged several inches, apparently because of the destruction of most of the sub-floor members. Early in April, part of the bedroom floor was removed for repairs and a detailed examination of the infestation was made.

## 2. Details of Infestation and Damage.

The bedroom floor, which was 14 ft. by 14 ft., was built of cypress pine (*Callitris glauca*), and although the termites had made extensive contact with the underside of the floor, and several runways were built over it at different points, there was no sign of any termite damage and the floor boards were as good as when they were laid nine years previously. The joists and bearers, however, were of local ash (almost certainly *Eucalyptus fastigata*) and each of the five bearers and nine joists had been destroyed. The extent of this damage can be gauged from the fact that in several places the joists had disappeared completely leaving, as the only evidence of their existence, rows of corroded nails projecting from the overlying flooring. Where the joists or bearers were still present, they consisted of little more than a paper-thin shell of wood through which it was possible to poke one's finger without any difficulty. The surface of these sub-floor members bore the dry and brittle remains of an extensive system of covered runways. For the most part these were $\frac{1}{2}$ in. to $\frac{3}{4}$ in. wide and rarely more than $\frac{1}{4}$ in. high, but in places they spread out into large continuous sheets of protective covering, extending several inches in each direction.

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From the lower surface of two of the joists, stalactite-like structures projected down towards the ground. These tubular projections, which were 3-4 in. long (one exceptional example measured 14 in.) and had a maximum diameter of $\frac{1}{4}$ in., had thicker and tougher walls than the runways. The function of these structures can only be surmised, but it appears most likely that they represent attempts by the termites to establish short-cut contacts with the soil.

The termites had gained access to the flooring by way of several clay-covered runways extending from the soil over the inside of the foundation walls to the joists and bearers. These runways, in contrast to those previously mentioned, were all occupied, and the steady to-and-fro traffic indicated that the colony was still at work somewhere in the house.

### 3. Treatment.

Since, at this stage, there did not appear to be much likelihood of locating the central nest of the attacking colony, it was decided to attempt its control by introducing poison into the occupied runways. Each of the ten runways on the foundation walls of the bedroom was opened, at ground level, just enough to permit the introduction of the nozzle of a de Vilbiss No. 36 powder blower. A few puffs of finely powdered white arsenic were blow into each runway and the opening closed with soil or a small chip of wood. In similar fashion, two runways beneath the floor of the adjacent sun-room (see Fig. 1) and about twelve under the verandah were treated. The total quantity of white arsenic used to treat all of these runways was less than $\frac{1}{4}$ oz.

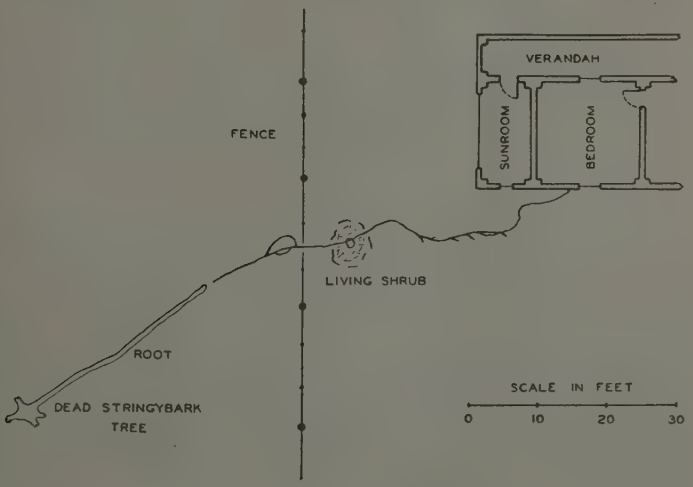


Fig. 1.—Sketch plan to show the details of the gallery connecting the main nest of *Coptotermes frenchi* with the infested house.

### 4. Central Nest and Gallery System.

The problem of locating the central nest in the non mound-building species of *Coptotermes* is a matter of some difficulty. In the present instance there were no old stumps or logs, such as might have housed the nest, either under or in the immediate vicinity of the house. However, 72 feet from the north-east corner was a recently dead stringybark (*Eucalyptus macrorrhyncha*), which is one of the many species of eucalyptus listed as host trees of *Coptotermes frenchi*.* An axe-cut through an exposed root of this tree revealed a large gallery along which considerable numbers of workers and soldiers of *C. frenchi* were passing, and this immediately suggested the possibility that there was a nest in the trunk of the tree. There has long been a strong suspicion that many house and building infestations by *C. frenchi* and by closely related *C. acinaciformis* are caused by colonies located in nearby living or dead trees, but to date no positive evidence on this point has been produced. It was considered worthwhile, therefore, to determine whether there was any connexion between the termites within the tree and those in the house.

The exposed root, mentioned above, was directed towards the house, and as this seemed a likely lead it was decided to trace out the gallery within this root. The gallery, which was roughly oval in section and ½ in. to ¾ in. in diameter, was followed along the root for 30 feet, at which point the root turned vertically downwards and the gallery passed out into the soil.

Shortly after leaving the root, the gallery descended at a steep angle to a depth of 2 feet, where it flattened out and ran in the general direction of the house. The depth at which it travelled was in marked contrast to that found for the galleries of *C. lacteus*,† most of which lie between 3 in. and 9 in. below the surface of the soil. Using essentially the same method as employed in the study referred to above, the gallery was followed through the soil by first puffing talc stained with methylene blue into the gallery and then opening up the exploratory trench along the assumed line of the gallery until the blue colouration revealed its exact position. The work was slow and difficult because of the depth at which the gallery ran (2 ft. to 2 ft. 6 in.) and the hardness of the soil, but eventually the gallery was traced, for a distance of 60 feet through the soil, to a point at which it passed under the foundation wall of the bedroom at a depth of 2 ft. 9 in.

The gallery in the soil was dark chocolate-brown in colour with the characteristic flecking on the inside walls. It was roughly lenticular in form, varying from ½ in. to upwards of 1¼ in. in width, with a fairly uniform height of ⅛ in. In some places, however, the height was increased to about ¼ in. and here the gallery was divided by horizontal septa into a double or even triple decked passage. Many side loops and branches were given off (see Fig. 1), but since almost all of these led away from the house they were not explored. The main gallery followed the course of an old root, which was recognizable merely as a "vein" of brown humus-like material through the

* Hill, G. F. (1942).—"Termites (Isoptera) from the Australian Region." (Melbourne.)

† Ratcliffe, F. N., and Greaves, T. (1940).—The subterranean foraging galleries of *Coptotermes lacteus* (Frogg.). *J. Coun. Sci. Ind. Res.* (Aust.) **13**: 150-161.

upper region of a red clay band lying some 2 feet below the surface of the soil. The gallery followed this or other root "veins," which either branched off or lay in close proximity, throughout the entire distance from the stringybark to the house.

Having demonstrated the connexion between the tree and the house, the next point was to find the nest. The stringybark, which had a diameter breast-high of 2 feet, was felled 3 feet above ground level and found to have a pipe about 4 in. diameter, packed with damp earthy material, as well as numerous large galleries in the true wood occupied by *C. frenchi*. Similar galleries were exposed in each of the radiating shallow roots cut during the grubbing out of the stump. This latter operation resulted in the discovery of the nest in the root crown and lower bole of the tree.

The nest actually extended from about 4 in. below ground level to 1 ft. 6 in., above ground level. It was roughly cylindrical in shape with an average diameter of 12 in. Two regions could be recognized, an outer wall of tough woody material containing many irregular galleries, and an inner "nursery" of brittle, thin-walled concentrically-arranged, flat chambers. A thorough examination of this nest structure revealed large numbers of recently dead termites which were producing moist, decaying patches in the central region. The actual population of living termites was quite small, no eggs or young were seen, and the colony appeared to be declining rapidly. There was no doubt, however, that the numerical strength of the colony had originally been sufficiently high to have caused the extensive damage within the house.

### 5. Discussion.

The detailed study of this infestation has been very valuable in focusing attention on certain aspects of termite activity and control, as well as bringing to light one or two new points.

In the first place the construction of the house was faulty, in that the walls of the bedroom were carried right to the soil without any provision for sub-floor ventilation. The dark, damp conditions beneath the floor were ideal for the termites, and coupled with the fact that there were no metal shields on the foundation walls nor caps on the floor piers, it is not surprising that the termites caused such extensive damage.

The extent of the damage shows the necessity, in areas where termites are troublesome, of employing resistant timbers for sub-floor members. This is especially true if no attempt is made to prevent the termites gaining access to such timbers. The contrast between the service performance of the cypress pine flooring and the ash joists and bearers was most striking, and whilst it is not suggested that cypress pine be used for sub-floor construction, there are several native hardwoods (e.g., red gum, tallowwood, grey ironbark, jarrah, and white mahogany) which have a very useful degree of resistance to termite attack, and under similar conditions to those described above would have given a much longer service life.

By far the most interesting feature, however, was the demonstration of the connexion between the house infestation and the tree-dwelling colony. This is the first occasion on which concrete evidence has been obtained to show that such a connexion may exist. In the present instance the infestation appears to have taken place in a

somewhat fortuitous manner. The more or less direct route of the gallery from the tree to the house was undoubtedly due to the fact that the gallery was constructed within an old root which happened to run in that direction. Presumably some type of surface scouting takes place periodically during the construction of such a gallery, and when such a scouting expedition encountered the susceptible timber in the house, general conditions were so suitable for large-scale activity that extensive damage resulted.

Additional information was also obtained on two points relating to the chemical control of termites. Firstly, the depth at which the gallery passed under the house wall is of considerable significance in relation to the practice of soil poisoning as a preventive measure. It is frequently recommended that soil treatments with arsenical solutions, creosote, &c., be applied to the top 12 in. or 18 in. of soil to prevent the ingress of termites. The present study has shown that whatever virtues such materials may possess are likely to be nullified if treatment is confined to the soil *outside* the foundation walls, since termites are able to pass under the walls at levels not reached by these chemicals. If soil treatment of building sites is to have any value, it will only be by the application of the toxic or repellent materials to the soil *inside* the walls and around floor piers and dwarf walls. In such situations the termites will be forced to pass through a treated region before they can gain access to the building. Secondly, the condition of the nest at the time of examination is considered to be due to the introduction of the white arsenic into the runways beneath the floor of the house. There is no positive proof of this point but very strong circumstantial evidence supports the belief. In a colony which is dying out from natural causes, such as the death of the king or queen, there is a slow decline in numbers without any obvious accumulation of dead bodies and, as a consequence, very little development of mould. In the nest described above, however, the reverse picture was seen with enormous numbers of dead and an excessive development of moisture and mould. Such conditions are characteristic of those found in mound colonies of termites following treatment with an effective poison, and they appear to be a natural consequence of a rapid and extensive mortality with which the still active members of the colony are unable to cope. There is no reason to believe that any of the mechanical operations associated with the tracing of the gallery seriously affected the colony, and the only logical conclusion appears to be that the runway treatments were responsible. The poison dust could not have been carried back to the nest through the excavated gallery since this was cut almost at the same time that the treatments were made. There were, however, galleries radiating out through every root of the stringybark and it is very probable that the connecting gallery which has been described, was only one of many which linked the tree colony with the house and which would have provided the necessary channels through which the poison could have been introduced during the eight-day period between the treatment of the runways and the grubbing out of the stump.

## 6. Acknowledgments.

My thanks are due to the owner of the property, Mr. E. G. McMurtrie, whose interest and co-operation made this investigation possible, and to J. H. Angus, of this Division, who carried out most of the tedious manual labour.

# Eradication of *Hydrocotyle tripartita* R.Br. from Golf and Bowling Greens

*By J. Griffiths Davies, B.Sc., Ph.D.,* and C. G. Greenham, M.Sc.†*

*Summary.*

An account is given of tests with 2,4-D (2,4-dichlorophenoxyacetic acid) and Methoxone (4-chloro-2-methyl-phenoxyacetic acid) for control of *Hydrocotyle tripartita* R.Br. in bowling and golf greens. Both substances gave almost perfect eradication of the weed when applied at the rate of 1 lb. per acre as a spray. The lawn grasses—browntop bent, *Agrostis tenuis* Sibth.; Chewing's fescue, *Festuca rubra* var. *fallax* Hack.; and Kentucky bluegrass, *Poa pratensis* L., were not injured in the slightest. Dinoc (sodium dinitro-o-cresylate) applied at the recommended rate scorched both the weed and the lawn grasses, but did not permanently injure either.

The effect of 2,4-D and Methoxone on some other lawn weeds is briefly referred to.

## 1. Introduction.

The weed *Hydrocotyle tripartita* R.Br.‡, variously known as pennywort, water weed, duck weed, carrot weed or cress, is extremely troublesome on golf and bowling greens and on well-kept household lawns in the Australian Capital Territory. The weed is widespread on both the Tableland and coastal areas of New South Wales (Whittet (8)), and it has been noted in Queensland on the Stanthorpe Bowling Club's green. Hardy (5) informs us that the weed is prevalent at Burnie in Tasmania. The same weed, or a closely allied species of the same genus, occurs in New Zealand, where it is so aggressive that some bowling clubs plant their rinks with it (Dickson (4)). In the U.S.A., three species of Hydrocotyle (*H. rotundifolia, H. bonariensis*, and *H. umbellata*) are recorded as lawn weeds (1, 2, 3).

In our experience, the weed is most troublesome in greens of browntop bent, *Agrostis tenuis* Sibth., or where this species is the dominant plant in association with Chewing's fescue, *Festuca rubra* var. *fallax* Hack., and Kentucky bluegrass, *Poa pratensis* L.

The weed attains almost complete dominance on bowling greens and can completely replace the grasses. On the more leniently cut golf greens, complete dominance is not as rapidly achieved, except on badly drained or heavily shaded areas.

*H. tripartita* is an undesirable weed in playing greens because—

(*a*) It produces a turf lacking in resiliency giving an uneven playing surface.

(*b*) The turf is not wear-resistant.

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† Physiologist (Weeds) of the Division of Plant Industry.

‡ We are indebted to Mr. R. H. Anderson, Chief Botanist and Curator, National Herbarium, Sydney, for a tentative identification in the absence of flowers or fruits.

(*c*) The absence of "nap" allows the ball or bowl to wander from the true line.

(*d*) Poor winter growth is made, at least under New South Wales Tableland conditions, and this makes for poor greens and facilitates entry of other weeds—notably *Poa annua* L., *Hypochaeris radicata* L., and *Taraxacum officinale* Weber.

(*e*) The turf is patchy, both in pace and colour. The dense mat-like "colonies" of *H. tripartita* vary in colour from bronze through yellowish green to bright green.

Control of the weed has been attempted by repeated applications of sulphate of ammonia or of a mixture of sulphates of ammonia and iron, at the rate of ¾ to 1 ounce per square yard. This treatment has served to check the weed temporarily, but it is less effective on bowling than on golf greens, and the weed has generally steadily increased in dominance. It is clear that the constant mowing, watering, and fertilizing required for the maintenance of the playing greens provide ideal conditions for the weed. The major factor is undoubtedly the close mowing which defoliates the more erect grasses to a greater extent than the horizontal leaves of the *Hydrocotyle*. The closer mowing on bowling greens accentuates this factor.

According to United States reports, a 0·1 per cent. solution of 2,4-dichlorophenoxyacetic acid (commonly referred to as 2,4-D) sprayed at the rate of 4 to 5 gallons per 1,000 square feet, has been effective in eradicating *H. rotundifolia* (1, 3), *H. bonariensis* and *H. umbellata* (1, 2). In England, Methoxone (4-chloro-2-methyl-phenoxyacetic acid) applied as a 0·1 per cent. solution at 100 gallons per acre has been found effective for the selective destruction of a number of "flatweeds" in cereal crops (7). In view of these reports, it was decided to ascertain if *H. tripartita* could be similarly controlled.

## 2. Investigations.

(i) *Initial Test.*

The initial small-scale test was made on the second tee at the Royal Canberra Golf Club to ascertain the safety of the treatments on the local turf grasses. The selected portion had an *H. tripartita* cover of 50 per cent. or more, the remaining cover being a mixture of *Poa pratensis* L. and *Agrostis tenuis* Sibth.

The following five spray treatments were applied at the rate of 100 gallons per acre (approximately 2½ gallons per 1,000 square feet):—

(1) Lawn Dinoc (sodium dinitro-o-cresylate). The commercial concentrated solution was diluted with 21 times its volume of water, as recommended by the manufacturers.

(2) Methoxone at 0·05 per cent. active concentration.

(3) Methoxone at 0·10 per cent. active concentration.

(4) A510 (an American preparation containing 70 per cent. 2,4-D), at 0·05 per cent. total concentration.

(5) A510 at 0·10 per cent. total concentration (0·07 per cent. of 2,4-D).

The spray solutions were applied during the afternoon of November 15, 1945. The plots were examined a few days later; both weed and grasses on the plot sprayed with Dinoc were decidedly scorched, whereas the grasses on the plots sprayed with the higher concentrations of Methoxone and A510 were only slightly scorched. On the night of November 16, 65 points of rain had fallen.

By November 30, there were no signs of injury to the grasses on any plot. Best results were obtained on the 0·1 per cent. Methoxone plot, which then had about 10 per cent. weed cover, and on the 0·1 per cent. A510 plot, with about 30 per cent. weed cover. There was a ground cover of about 60 per cent. weed left on the Dinoc plot.

(ii) *Tests with 2,4-D.*

(*a*) In view of the above results, the fifteenth green of the Royal Canberra Golf Club was sprayed with 0·1 per cent. A510 (i.e., 0·07 per cent. 2,4-D). On this green, which is partially shaded, the concentration of the weed increased from the well-drained periphery (about 5 per cent. weed cover) to the poorly drained depressed centre (80-100 per cent. weed cover). Spraying was done on February 26, 1946, with an ordinary knapsack spray pump giving a fan-shaped spray. The area was sprayed twice, at a total rate of 100 gallons per acre; the second application was done at right angles to the first. The day was dull, with considerable wind (5 degrees Beaufort); about 20 points of rain fell during the night.

The weed became yellow within the next few days. On March 11 it was clear that the effectiveness of the kill was greater near the periphery, formerly lightly infested, than at the heavily infested centre, where the almost complete dominance of the weed was still but slightly affected. Cord lines had been used as guides in spraying: it was observed that a complete kill of the weed was obtained on belts about 2 inches wide, in the neighbourhood of these lines. This was obviously caused by the additional spray in the immediate vicinity of the lines. Although the grass in these belts was initially slightly injured, a very dense and dark green cover of grass developed in them. These observations suggested that a greater volume or higher concentration of the spray solution could have been used.

The green was fertilized with sulphate of ammonia at $\frac{3}{4}$ oz. per square yard on March 12, and seeded with *Agrostis tenuis*. On April 29, this green was in markedly better condition than previously. Approximately two-thirds of the green was practically free from the weed, whilst the depressed centre now carried about 40 per cent. grass cover, except in two areas of 1—2 square feet where the original heavy weed cover was still present. On this day the green was sprayed again —this time with 0·1 per cent. Methoxone at 100 gallons per acre. This spray application effectively eradicated the remaining weed. The turf grasses, *Agrostis tenuis, Poa pratensis,* and *Festuca rubra* var. *fallax* (Chewing's fescue), remained unaffected by the spraying. *Poa annua* L. rapidly colonized the completely bare areas in the green.

(*b*) An additional test was made on the practice putting green of the Royal Canberra Golf Club, which had a 50 per cent. ground cover of vigorous *Hydrocotyle*. Plate 1, Fig. 1, shows a typical weedy area.

The green had been given an application of sulphate of ammonia, at ¾ oz. per square yard, a week before spraying. The spray solution was applied on the afternoon of March 19, in bright sunshine and slight breeze (1 degree Beaufort). The spray was applied at the rate of 100 gallons per acre, and consisted of 0·1 per cent. 2,4-D, dissolved in water with the aid of twice its weight of sodium bicarbonate. Accordingly, the concentration of 2,4-D in this spray solution was nearly one and one-half times that in the A510 solution used previously in the initial tests.

The putting green was examined on March 28, the sprayed area having been left uncut since March 18. There had been an excellent kill of the weed. The uncut strips about a foot wide outside the sprayed area were of interest. These strips showed how, by allowing the lawn to grow away a little, the weed was forced upward. When mowed on March 28, the weed suffered considerably greater defoliation than obtains when the greens are cut at normal height and frequency (Table 1).

Table 1.

| | Sprayed, not Cut. | | Not Sprayed, not Cut. | | Control (Not Sprayed, Cut). | |
|---|---|---|---|---|---|---|
| | Weed. | Grass. | Weed. | Grass. | Weed. | Grass. |
| | % | % | % | % | % | % |
| Estimated relative weights of grass and weed, 28th March, 1946 | 3·27 (S.E. ·95) | 96·73 | 32 (S.E. 5·15) | 68·0 | 72·5 (S.E. 6·25) | 27·5 |
| Estimated relative ground cover of grass and weed, 29th March, 1946 (after cutting) | 0·29 (S.E. ·022) | 99·71 | 30·0 (S.E. 3·10) | 70·0 | 55·29 (S.E. 5·12) | 44·71 |

Quadrat counts per square link made on the sprayed area and surrounding portions are also given in Table 1. The data on the uncut, unsprayed area is to be regarded with some reserve because the strip probably received some spray drift, though the clear-cut distinction at the edge of the sprayed plot indicated that the amount of spray overlap was slight.

The putting green was mowed to schedule after March 28, i.e., every two days. When the sprayed portion was examined on April 29, only two *Hydrocotyle* leaves could be found. Plate 1, Fig. 2, shows portion of the sprayed area. Square-link counts on the surrounding unsprayed area gave an average weed cover of 42·0 per cent. (S.E. 6·02). It was noticed that the grass (*Agrostis tenuis*) on the sprayed area was greener than that on the unsprayed portions. The stimulation of the sprayed sward was still obvious on June 6. Stimulation of grasses resulting from the application of 2,4-D has already been recorded (2).

(*c*) During March 1946, spot tests were also made on the putting green with 0·1 per cent. 2,4-D in sodium bicarbonate solution, containing in addition 30 per cent. nitrate of soda or sulphate of ammonia. The solutions, applied at 100 gallons per acre, gave the equivalent of 1 oz. of fertilizer per square yard. The *Hydrocotyle* was killed, but the grass was severely scorched, even killed in patches, and recovered slowly. Obviously the concentration of fertilizers was too high.

(iii) *Tests with Methoxone.*

(*a*) The promising results with Methoxone in the initial test on *Hydrocotyle* were followed by a test on the City Bowling Club's green at Braddon, A.C.T. This green was heavily infested with *Hydrocotyle* which occurred in more or less circular patches 1 to 3 feet in diameter. The grass cover in these dense patches was less than 0·5 per cent. The green had originally been seeded down to a mixture of *Agrostis tenuis* and *Festuca rubra* var. *fallax*. Plate 2, Fig. 1, shows portion of a typical *Hydrocotyle* colony before spraying, which was done in the morning of February 28, 1946, in bright sunshine with a little breeze (2 degrees Beaufort). The spray solution consisted of 0·1 per cent. Methoxone, and was applied at 100 gallons per acre, in two applications at 50 gallons per acre, the direction of the second application being at right angles to that of the first. In this instance, chalked lines were used as guides.

The sprayed area was examined on March 29, having been given normal maintenance and use in the meanwhile. The weed was dead in most of the sprayed area, but still gave about 40 per cent. cover in some of the dense patches. There had been no injury to the grasses. A final examination was made on April 29. The weed had made no recovery where it had originally been killed. The maximum cover of weed elsewhere was reduced to about 0·5 per cent., but this weed appeared to be making fresh growth. It is possible that these weedy areas had been lightly sprayed, because the spraying was not done by a skilled operator. It was noted that *Poa annua* was becoming established on the bare areas formerly covered by the weed. Plate 2, Fig. 2, shows a former weedy area after spraying.

(*b*) In the course of spraying some of the aprons at the Royal Canberra Golf Club with 0·1 per cent. Methoxone at 200 gallons per acre, some catsear plants (*Hypochaeris radicata* L.) were sprayed. The leaves of these plants soon became epinastic and died, and the upper portions of the roots died also. At this stage, it is uncertain if the catsear was killed to sufficient depth to prevent regrowth, but it is certain that considerable damage was done to this weed, aiding the grass to cover patches formerly occupied by it.

Other species showing sensitivity to Methoxone included: *Achillea Millefolium* L., *Salvia Verbenaca* L., *Taraxacum officinale* Weber.

### 3. Discussion.

2,4-D and Methoxone at 0·1 per cent. concentration applied at 2½ gallons per 1,000 square feet, are both very effective in eradicating *Hydrocotyle tripartita* from golf and bowling greens. Complete eradication may be possible in one application. It is of interest to note that good control was obtained at half the rate recommended in the American

literature. However, recent evidence from local investigations suggests that more certain results can be expected under a wide range of conditions by using the American rate of application. Temporary injury to *A. tenuis* has been recorded in the U.S.A. from 5 gallons of 0·1 per cent. of 2,4-D but no indication of this has been noted in these trials.

In later sprayings to deal with the greens and aprons at the Royal Canberra Golf Club it was found convenient to apply by knapsack 1¼ gallons per 1,000 square feet. Two such sprayings three to four weeks apart give a complete eradication of the weed. An advantage of two such applications on turf heavily infested with *Hydrocotyle* is that the first spraying allows increased growth of the grass before the weed is finally killed, thus minimizing bare patches.

It may also be mentioned that with *Hydrocotyle,* the action of Methoxone or 2,4–D is slower in cold weather than in hot.

The observations on the putting green (Test ii (*b*)) suggest that, where possible, the playing greens should be rested for 8 to 10 days. This rest period will, of itself, give the lawn grasses a decided advantage over the weed, due to competition. It is to be noted that Mitchell and Brown (6) have already indicated that the tops of certain weeds should not be mowed *after spraying,* because defoliation within a few hours of applying 2,4–D to leaves lessens or inhibits the effects of that substance. Absence of mowing doubtless helped obtain the excellent kill of the *Hydrocotyle* reported herein for the practice putting green (Test ii (*b*)).

## 4. Acknowledgments.

It is desired to acknowledge the help received from Mr. L. D. Pryor, Superintendent of Parks and Gardens, and from Mr. L. Robinson, Greenkeeper at the Royal Canberra Golf Club.

The A510 was supplied by the Dow Chemical Co., Michigan, U.S.A. The 2,4–D was presented by Taubmans Ltd., Sydney. The Methoxone was supplied by Imperial Chemical Industries of Australia and New Zealand Ltd., Melbourne.

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# Studies on Chemical Weed-killers with Special Reference to Skeleton Weed (*Chondrilla juncea* L.)

## 5. Preliminary Trials with Hormone-like Weed-killers

*By C. G. Greenham, M.Sc.**

*Summary.*

An account is given of preliminary trials with five hormone-like substances and some commercial preparations, on skeleton weed. The spray solutions were applied at 100 gallons per acre.

α-naphthylacetic acid, 2-methyl phenoxyacetic acid, 2, 4-dichlorophenoxyacetic acid, 4-chloro-2-methyl phenoxyacetic acid, and α-naphthoxyacetic acid, at approximately 0·1 per cent. concentration in 0·5 per cent. triethanolamine, did little more than kill a few leaves and cause epinasty of stems within eighteen days. Evidence was obtained that 4-chloro-2-methyl phenoxyacetic acid was possibly the most toxic.

A spray solution consisting of 7·5 per cent. arsenic pentoxide within eighteen days killed the roots of all sprayed plants to a depth of at least 20 inches.

It was found that the effect of Dow "A510" (2, 4-dichlorophenoxyacetic acid) and Methoxone (4-chloro-2-methyl phenoxyacetic acid) increased with concentration, also that the former was less effective than the latter, though neither gave promise of controlling the weed under the conditions of the experiment.

After ten weeks 2·7 per cent. Methoxone killed skeleton weed roots to an average depth of 1·7 inches, but re-growth had then occurred.

### 1. Introduction.

Investigations on chemical weed killers with special reference to skeleton weed ceased in 1940.

With the resumption of peace-time activities, some attention is again being given to this weed. The weed is not regarded as seriously as previously (2, 8), because farmers have been able to make a living in its presence by turning their land over to pasture for the production of fat lambs. The weed, however, is still a pest in areas where wheat farming is practised, particularly in view of the present need for that crop. Further investigations on the chemical control of the weed are desirable also because the weed is spreading and because, owing to its peculiar growth form, it is an ideal weed for a study of the penetration and translocation of poisons.

Within the last few years it was discovered in England (1, 11) and America (6, 7, 9, 10) that hormone-like substances, applied at comparatively low concentrations, give excellent control of many weeds. Recently it was found (3) that such substances give good control of *Hydrocotyle tripartita* R. Br., a shallow-rooted perennial weed in Australia. Some of the overseas reports (6, 7, 9) refer to the value of hormone-like substances as translocated poisons, such as are needed for the chemical control of skeleton weed. Other reports (1, 7, 9, 11) refer to the selective action of such substances on flat weeds in grasses and cereals. There is a need for a translocated spray for the control of skeleton weed, particularly one which would have a selective action on the weed in wheat.

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The present paper describes preliminary experiments on skeleton weed with hormone-like weed-killers.

## 2. Experimental.

*Experiment* 1.

This experiment, with a number of hormone-like substances, was done in an endeavour to determine their comparative toxicity or effectiveness as weed-killers.

The substances listed in Table 1 were used. The 4-chloro-2-methyl phenoxyacetic acid was used at 0·1 per cent. concentration. Unless otherwise stated, the other substances were used at the corresponding equimolecular concentration. With the exception of the two commercial preparations, all the substances were dissolved in 0·5 per cent. triethanolamine (13), which also acts as a wetter. Carbowax 1500, which has been used fairly extensively as a solvent for hormone-like substances (6, 7, 9, 10), was not available.

At the Dickson Experiment Station, A.C.T., 80 skeleton weed plants, in ten groups of eight plants, as uniform as possible, were selected. The plants were at the stage considered optimal for spraying (4, Pt. 1). The spray solutions were applied to individual plants at from 5.30 a.m. to 6.30 a.m. on November 9, 1945, at 100 gallons per acre and according to the technique previously devised (4, Pt. 2). The temperature and relative humidity at 5.30 were 68°F. and 49 per cent., and at 6.30 were 72°F. and 47 per cent. The spray applications were made early in the morning to avoid a possible time-of-day effect (4, Pt. 3), and in an endeavour to avoid strong winds. However, at the time of application there was a wind of 5 degrees Beaufort. Shields were used to enable plants to be sprayed without loss. During the night of November 9 8 points of rain fell, and 96 points during the following night.

*Results.*—After the application of the sprays, the stems of some plants became epinastic, or leaves became discoloured or died. It was necessary to conclude the experiment by November 27. As the subterranean axis (4, Pt. 1) of sprayed plants had not been killed, it was decided to give a numerical rating to the reactions of the sprayed plants, as shown in Table 1. The more severe the reaction, the higher is the rating; the rating need not be a linear function of the extent of the reaction.

Table 1.—Rating of Effects on Sprayed Plants, November 27, 1945.

| Treatment. | Mean Rating. |
|---|---|
| α–naphthyl acetic acid | 1·3 |
| 2–methyl phenoxyacetic acid | 0·7 |
| 2, 4–dichlorophenoxyacetic acid (sample *a*) | 1·8 |
| Methoxone (commercial 4–chloro–2–methyl phenoxyacetic acid), at 0·1 per cent. active acid content | 1·7 |
| 2, 4–dichlorophenoxyacetic acid (sample *b*) | 1·3 |
| 4–chloro–2–methyl phenoxyacetic acid, 0·1 per cent. | 2·2 |
| α–naphthoxyacetic acid | 1·1 |
| Dow "A510" (commercial 2, 4–dichlorophenoxyacetic acid) at 0·1 per cent. active acid content | 1·0 |

Ratings used :—0, plants unaffected; 1, stems epinastic and/or few leaves slightly discoloured; 2, few leaves discoloured; 3, all or nearly all leaves discoloured; 4, few leaves killed; 5, nearly all leaves killed; 6, stem and leaves killed, axis killed to a definite depth.

TABLE 2.—ANALYSIS OF VARIANCE.—EXPERIMENT 1.

| Source of Variation. | Degrees of Freedom. | Sums of Squares. | Mean Square. | F. | Significance. |
|---|---|---|---|---|---|
| Replications .. .. .. | 9 | 14·9 | 1·656 | | |
| Treatments .. .. .. | 7 | 16·5 | 2·357 | 1·87 | N.S. |
| Error .. .. .. | 63 | 79·6 | 1·263 | | |

Minimum difference between means for significance at 5 per cent. level, 1·0.
Minimum difference between means for significance at 1 per cent. level, 1·3.

From Tables 1 and 2 it is seen that the 4-chloro-2-methyl phenoxyacetic acid treatment is possibly more effective than the rest, between which one cannot discriminate.

*Experiment 2.*

This experiment was done in order to obtain an idea of the concentrations of A510 and Methoxone required for the control of skeleton weed. Arsenic pentoxide, at 7·5 per cent. concentration, was included to give a basis of comparison with former work (5). The spray solutions used are listed in Table 3.

At the Dickson Experiment Station, 90 skeleton weed plants, at the stage considered optimal for spraying, were selected. Owing to insufficiency of numbers, the plants could not be selected in groups. The treatments were superimposed upon plants selected at random. The spray treatments were applied on November 9, 1945, at from 6.30 a.m. to 8 a.m., the temperature and relative humidity at the latter time being 82°F. and 37 per cent. As in the previous experiment, there was considerable wind (5 degrees Beaufort). The same technique was used.

The stems of most plants sprayed with the hormone-like substances became epinastic; in only one instance was leaf epinasty observed. Discoloured leaves turned reddish or yellow, and some died. In none of the sprayed plants did the subterranean axis show swelling or other forms of growth response. In plants sprayed with the arsenic pentoxide the leaves soon became yellow and died.

The subterranean axes of sprayed plants were excavated on November 27 and 28. In determining the depth to which they were killed, use was made of the latex test (4, Pt. 1) supplemented with a new test in which the electrical resistance between two points of a probe is measured. It is well known that living tissue has a high resistance and dead tissue a low resistance. This electrical test proved very satisfactory.

Table 3 gives the results obtained.

TABLE 3.

| Treatment. | Mean Rating. | Mean Depth of Kill. |
|---|---|---|
| | | in. |
| $As_2O_5$, 7·5 per cent. .. .. .. .. | 6·0 | 23·35 ± ·82 |
| Methoxone 0·1 per cent. (active acid content) .. | 2·4 | 0 |
| ,, 0·3 per cent. .. .. .. | 2·9 | 0 |
| ,, 0·9 per cent. .. .. .. | 3·8 | 0 |
| ,, 2·7 per cent. .. .. .. | 4·7 | 0 |
| ,, 8·1 per cent. .. .. .. | 5·9 | 1·98 ± ·27 |
| A510 0·1 per cent. (active acid content) .. .. | 1·2 | 0 |
| ,, 0·3 per cent. .. .. .. .. | 1·8 | 0 |
| ,, 0·9 per cent. .. .. .. .. | 3·0 | 0 |

Ratings as in Table 1.

Treatments comprising 7·5 per cent. arsenic pentoxide and 8·1 per cent. Methoxone were excluded from the analysis of variance, because of their relative uniformity of rating owing to almost all shoots being killed. Table 4 gives a statistical summary for the remaining treatments.

TABLE 4.—ANALYSIS OF VARIANCE.—NUMERICAL RATINGS.—EXPERIMENT 2.

| Source of Variation. | Degrees of Freedom. | Sums of Squares. | Mean Square. | F. | Significance. |
|---|---|---|---|---|---|
| Treatments .. .. | 6 | 83·7 | 13·95 | 30·86 | $P < ·001$ |
| Error .. .. .. | 63 | 28·5 | ·452 | .. | .. |

Minimum difference between treatment means for significance—
at 5 per cent., 0·6
at 1 per cent., 0·8

From Table 3 it is seen that the arsenic pentoxide treatment was the most effective of all, followed by the treatment comprising 8·1 per cent. Methoxone. From Tables 3 and 4 it is seen that both with Methoxone and A510, the effects of treatments increase with concentration, also that the Methoxone treatments are significantly more effective than corresponding A510 treatments.

*Experiment* 3.

It was realized that hormone-like poisons may be slow in action, and that the results recorded above refer to observations eighteen to nineteen days after spraying. Another experiment was accordingly done, to eliminate any time factor.

In this experiment, plants were selected at Black Mountain, A.C.T. These plants were also developing stems. This growth out of season had been obtained by cutting back the plants about a month previously. Spraying was done with 2·7 per cent. Methoxone (active content), at

100 gallons per acre, during the early afternoon of February 27, 1946. The afternoon was sunny, but windy (6 degrees Beaufort). There was no fall of rain in the next eight days.

The first batch of six plants was excavated on the 28th March. The depth of kill varied from $1\frac{1}{4}$ in. to $3\frac{3}{4}$ in. (mean 2·04 in., S.E. 0·34). The remaining 27 plants were excavated on May 8, 1946, when it was found that the depth of kill varied from 1 in. to $2\frac{1}{2}$ in. (mean 1·65 in., S.E. 0·42). All but four of the latter plants were making new growth; most had formed new rosettes.

### 3. Discussion and Conclusions.

In experiment 1, there is evidence that the 4-chloro-2-methyl phenoxyacetic acid is possibly more toxic than the other substances tested. This is in accordance with English reports (11) that on annual weeds it is more active than α-naphthylacetic acid and α-naphthoxyacetic acid.

It is realized that the poor responses obtained in experiments 1 and 2 may be due to the comparatively short interval (18-19 days) between spraying and examination, or to the 8 points of rain which fell within 24 hours of application. Hormone-like weed-killers may be slow in action, moreover, it is reported (12) that heavy rainfall within 24 hours of application of 2, 4-dichlorophenoxyacetic acid reduces its effectiveness to a marked degree. In experiment 3, much better responses were obtained after 29 days, which is not a much greater interval than nineteen days. In fact, in experiment 3, better responses were not obtained after ten weeks, by which time most plants were producing fresh leaves. It is to be noted that the plants in experiment 3 had previously been cut back, and this defoliation may have made the plants more susceptible. It is quite likely, however, that the rain had a deleterious effect on the spray applications in experiments 1 and 2.

In spite of the rain falling within 48 hours after the application of the spray solutions in experiment 2, good results were obtained with the 7·5 per cent. arsenic pentoxide. This confirms former observations (5). The results in experiment 2 indicate that a useful degree of control of the weed can be obtained with 7·5 per cent. arsenic pentoxide, in view of former observations on the effect of killing skeleton weed to a depth of 2 feet (4, Pt. 1). Further investigations with arsenic pentoxide are accordingly desirable.

In experiment 3, an average depth of kill of 2 inches or less was obtained, which is valueless for the control of the weed. The concentration of Methoxone was high, viz., 2·7 per cent., and such a concentration is costly. As experiment 2 shows that the effect of a spray solution depends on concentration, economic control of skeleton weed by Methoxone is unlikely, unless methods of application can be improved, or unless a more susceptible growth stage of the weed can be found.

### 4. Acknowledgments.

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Methoxone—Imperial Chemical Industries of Australia and New Zealand Ltd., Melbourne; α-naphthoxyacetic acid—Dr. F. Reuter, Sydney Technical College. 2, 4-dichlorophenoxyacetic acid was also donated by the C.S.I.R. Division of Industrial Chemistry, Melbourne. The Dow "A510" was supplied by the Dow Chemical Co., Michigan, U.S.A.

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# Some Observations on the Magnitude of Agronomic Variation within Cabbage Varieties and a Description of Varieties.

*By D. C. Wark, M.Agr.Sc.**

*Summary.*

During 1944, at Canberra, A.C.T., and during 1945, at both Canberra, A.C.T., and Griffith, New South Wales, a number of strains of the more common varieties of cabbage were grown in the field. Agronomic observations were made during growth and at harvest.

The percentage of marketable heads produced by each strain was recorded. Representative samples were weighed and the width and depth of the heads measured.

The percentage of marketable heads produced by any strain of cabbage was found to be influenced by the environmental conditions under which it was grown. There were also large differences between strains of the one variety.

A number of the leading varieties of cabbage are described briefly.

## 1. Introduction.

The observations reported in this paper concern the effects of environment and strain on the agronomic features of a number of cabbage varieties, including both imported and Australian-grown seed. These were supplied by the Commonwealth Vegetable Seeds Committee and were grown during the 1944 season at Canberra, A.C.T., and during the 1945 season at Griffith, New South Wales.

Sixty of the seed samples were planted three times, so that they matured under three sets of climatic conditions, namely—

(i) The cold winter at Canberra (sown January, 1944, transplanted March, 1944, and harvested July, 1944).

(ii) The warmer summer temperatures at Canberra (sown July, 1944, transplanted September, 1944, and harvested January, 1945).

(iii) The medium temperatures of autumn to winter at Griffith (sown January, 1945, transplanted February, 1945, and harvested July, 1945).

The temperatures of these two sites are compared in Table 1, on the basis of average monthly temperatures, average daily maximum and minimum temperatures, and the extreme maximum and minimum temperatures recorded during each month.

Thus cabbages maturing in July, 1944, at Canberra were subjected to average monthly temperatures of 45·9°, 35·7°, and 38·5°F. during May, June, and July respectively. The extreme maximum temperature during this period was 68°F. and the extreme minimum temperature was 16°F. There were severe frosts during which the temperature fell to several degrees below freezing point. These severe conditions were reflected in the small size of the cabbages and in the low proportion of marketable heads.

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TABLE 1.—AVERAGE TEMPERATURES, AVERAGE MAXIMUM AND MINIMUM TEMPERATURES, AND EXTREME MAXIMUM AND MINIMUM TEMPERATURES RECORDED AT CANBERRA AND AT GRIFFITH DURING THE YEARS 1944 AND 1945.

| | Canberra Temperatures (°F.). | | | | | | | | | | Griffith Temperatures (°F.). | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1944. | | | | | 1945. | | | | | 1944. | | | | | 1945. | | | | |
| | Av. | Av. Max. | Av. Min. | Ext. Max. | Ext. Min. | Av. | Av. Max. | Av. Min. | Ext. Max. | Ext. Min. | Av. | Av. Max. | Av. Min. | Ext. Max. | Ext. Min. | Av. | Av. Max. | Av. Min. | Ext. Max. | Ext. Min. |
| January .. .. | 72·9 | 86·7 | 51·7 | 99·0 | 41·0 | 68·5 | 85·8 | 54·1 | 104·0 | 32·0 | 75·9 | 91·8 | 60·0 | 104·9 | 51·8 | 74·3 | 88·2 | 60·4 | 106·3 | 48·1 |
| February .. .. | 66·6 | 82·4 | 50·5 | 95·0 | 35·0 | 63·9 | 79·3 | 52·5 | 94·0 | 36·0 | 67·8 | 83·6 | 52·0 | 101·4 | 48·1 | 71·6 | 85·5 | 57·6 | 100·1 | 45·9 |
| March .. .. .. | 60·9 | 78·0 | 46·4 | 89·0 | 36·0 | 59·7 | 74·7 | 47·2 | 85·0 | 36·0 | 67·5 | 80·8 | 54·2 | 95·0 | 42·1 | 64·6 | 79·8 | 49·4 | 92·9 | 40·0 |
| April .. .. .. | 53·0 | 66·9 | 37·9 | 86·0 | 26·0 | 53·4 | 65·7 | 43·9 | 73·0 | 25·0 | 56·7 | 68·8 | 44·6 | 92·7 | 34·2 | 59·1 | 73·7 | 44·4 | 81·1 | 30·4 |
| May .. .. .. | 45·9 | 59·3 | 36·9 | 68·0 | 26·0 | 44·3 | 58·1 | 34·5 | 68·0 | 21·0 | 52·6 | 61·5 | 43·7 | 75·8 | 34·6 | 53·1 | 65·9 | 40·3 | 79·9 | 31·9 |
| June .. .. .. | 35·7 | 52·1 | 26·3 | 58·0 | 16·0 | 45·3 | 54·4 | 37·9 | 63·0 | 24·0 | 46·6 | 58·7 | 34·5 | 71·9 | 24·5 | 52·0 | 62·1 | 41·9 | 69·5 | 29·8 |
| July .. .. .. | 38·5 | 52·0 | 29·8 | 58·0 | 18·0 | 37·1 | 50·2 | 29·3 | 56·0 | 17·0 | 45·4 | 57·1 | 33·7 | 67·1 | 24·2 | 45·2 | 55·5 | 34·8 | 63·8 | 24·4 |
| August .. .. .. | 42·3 | 56·6 | 30·8 | 66·0 | 18·0 | 45·7 | 54·3 | 35·5 | 59·0 | 22·0 | 46·7 | 57·3 | 36·1 | 69·3 | 27·1 | 51·4 | 61·3 | 41·4 | 69·5 | 33·2 |
| September .. .. | 50·0 | 63·3 | 33·4 | 76·0 | 21·0 | 48·5 | 59·7 | 35·3 | 72·0 | 25·0 | 57·2 | 71·4 | 42·9 | 87·9 | 28·0 | 53·1 | 66·0 | 40·2 | 83·1 | 27·7 |
| October .. .. | 59·5 | 71·2 | 37·5 | 88·0 | 21·0 | 57·5 | 67·6 | 40·6 | 84·0 | 29·0 | 62·7 | 76·6 | 48·7 | 95·9 | 37·8 | 60·2 | 73·2 | 47·2 | 92·9 | 32·2 |
| November .. .. | 67·2 | 80·4 | 48·2 | 102·0 | 32·0 | 63·6 | 74·0 | 47·3 | 89·0 | 31·0 | 71·0 | 84·9 | 57·1 | 106·8 | 42·6 | 68·2 | 81·7 | 54·7 | 104·6 | 42·2 |
| December .. .. | 67·9 | 80·0 | 51·1 | 96·0 | 40·0 | 70·1 | 83·8 | 51·7 | 100·0 | 41·0 | 70·3 | 85·1 | 55·4 | 99·3 | 46·1 | 75·5 | 92·1 | 58·9 | 112·5 | 45·1 |

The cabbages maturing in January, 1945, experienced average monthly temperatures of 67·2°, 67·9°, and 68·5°F. for the corresponding three months of their life history, the extreme range of temperatures being from 104° to 32°F.

Those maturing at Griffith during the month of July, 1945, experienced average monthly temperatures of 53·1°, 52·0°, and 45·2°F, for the months of May, June, and July respectively. The extremes of temperature during this period were 80° and 30°F.

As the cabbages were grown under irrigation at both centres, differences in rainfall are less important than temperature differences.

### 2. Cultural Methods and Observations Made.

From each seed line, duplicate rows of 30 plants were transplanted into the field. The rows were 2 ft. 4 in. apart at Griffith and 3 ft. 4 in. apart at Canberra, the seedlings being spaced 2 feet apart in the rows at both centres.

At harvest, the numbers of typical and marketable heads of each variety were counted and twelve marketable heads of each variety were measured. The heads to be measured were sampled at random and the following measurements were made on them:

(i) The cabbage was cut at ground level and weighed to the nearest 10 grams, with all the outside leaves attached. This measurement is referred to as the "unstripped weight" of the cabbage.

(ii) All the external leaves were removed and the stem was cut off level with the base of the heart, which was then weighed. This measurement is referred to as the "stripped weight".

(iii) The vertical distance from the stem cut to the crown of the head was measured to the nearest 1/10 inch.

(iv) The horizontal diameter of the head was measured.

The ratio of the width to the height was used as an index of the shape of the cabbage. The proportion of the weight lost in stripping was also determined as an index of efficiency of growth from the commercial point of view.

### 3. The Effect of Environment.

Of the seed lines included in two or more plantings, the majority produced a lower proportion of marketable heads when they matured under the winter conditions at Canberra (i.e. transplanted during the month of February), than when they matured under summer conditions at Canberra (transplanted September) or under winter conditions at Griffith (transplanted February).

Of the 67 seed lines grown to maturity under cold and less cold conditions, 33 produced a significantly* lower proportion of marketable heads under the colder conditions (harvested at Canberra in July). Only one seed line produced a significantly higher proportion of marketable to total heads in the July harvest at Canberra than in both the January harvest at Canberra and the July harvest at Griffith. This was the only strain of the variety Greenleaf cabbage that was included in this examination of strains. The only tested seed line of the variety Irish cabbage produced significantly fewer marketable heads in the

* $P = < \cdot 05$.

January harvest at Canberra than in either of the July harvests. Some strains of Golden Acre and Copenhagen Market also produced more marketable heads in the July harvests than in the January harvest. In general, larger heads were produced at Griffith than at Canberra, and of the two harvests at Canberra, the January harvest produced the larger cabbages.

Actual measurements of two strains of five of the more common varieties are shown in Table 2. The varieties included are Early Jersey Wakefield, Golden Acre, Copenhagen Market, Succession, and Enkhuizen Glory.

TABLE 2.—GROWTH RECORDS OF STRAINS OF CABBAGE VARIETIES UNDER DIFFERENT ENVIRONMENTAL CONDITIONS.

| Variety. | Strain. | Harvest.* | Marketable Heads. | Head Weight. | | Lost in Stripping. | Average Dimensions. | | Ratio. Width/Height. | Yield per Acre. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Unstripped. | Stripped | | Width. | Height. | | |
| | | | % | kg. | kg. | % | in. | in. | | tons. |
| Early Jersey Wakefield | CB3 | C4 | 50·0 | 0·6 | 0·2 | 63·5 | 2·7 | 3·9 | 0·7 | 0·8 |
| | | C5 | 55·2 | 1·2 | 0·4 | 66·7 | 3·7 | 5·7 | 0·7 | 1·5 |
| | | G | 80·6† | 1·4 | 0·8 | 46·4 | 4·7 | 7·4 | 0·6 | 5·6 |
| | CB41 | C4 | 87·5 | 1·5 | 0·6 | 56·5 | 5·3 | 6·4 | 0·8 | 3·7 |
| | | C5 | 90·9 | 1·5 | 0·5 | 64·7 | 4·1 | 5·4 | 0·8 | 3·2 |
| | | G | 94·0† | 1·9 | 1·0 | 40·7 | 5·2 | 7·6 | 0·7 | 8·7 |
| Golden Acre | CB2 | C4 | 87·5‡ | 1·1 | 0·6 | 47·7 | 5·2 | 4·8 | 1·1 | 3·4 |
| | | C5 | 66·0 | 2·1 | 1·3 | 36·9 | 5·9 | 5·8 | 1·0 | 5·7 |
| | | G | 90·0‡ | 3·0 | 2·1 | 30·2 | 6·5 | 6·8 | 1·0 | 17·2 |
| | CB31 | C4 | 83·3‡ | 1·0 | 0·5 | 45·6 | 4·6 | 4·6 | 1·0 | 3·0 |
| | | C5 | 68·3 | 1·6 | 1·0 | 38·9 | 5·3 | 4·9 | 1·1 | 4·5 |
| | | G | 89·0‡ | 2·3 | 1·5 | 33·4 | 6·9 | 5·3 | 1·3 | 12·3 |
| Copenhagen Market | CB5 | C4 | 83·3‡ | 1·1 | 0·6 | 46·7 | 5·2 | 5·0 | 1·0 | 3·3 |
| | | C5 | 69·0 | 1·1 | 1·0 | 12·0 | 5·5 | 5·8 | 1·0 | 4·5 |
| | | G | 94·9†‡ | 2·0 | 1·3 | 35·2 | 7·1 | 5·9 | 1·2 | 11·3 |
| | CB36 | C4 | 66·7 | 1·0 | 0·4 | 55·8 | 4·4 | 4·0 | 1·1 | 1·9 |
| | | C5 | 61·8 | 1·6 | 0·9 | 42·9 | 5·6 | 5·1 | 1·1 | 3·7 |
| | | G | 90·0†‡ | 2·5 | 1·8 | 29·1 | 7·4 | 7·3 | 1·0 | 14·7 |
| Succession .. | CB46 | C4 | 40·0 | 1·5 | 0·5 | 65·4 | 5·3 | 4·2 | 1·3 | 1·3 |
| | | C5 | 71·7† | 2·3 | 1·4 | 40·0 | 7·9 | 4·5 | 1·8 | 6·4 |
| | | G | 55·2† | 3·8 | 2·3 | 38·4 | 9·3 | 6·4 | 1·5 | 11·8 |
| | CB58 | C4 | 33·3 | 1·1 | 0·3 | 71·0 | 5·0 | 3·6 | 1·4 | 0·7 |
| | | C5 | 41·5†‡ | 2·0 | 1·2 | 40·0 | 6·7 | 4·6 | 1·5 | 3·4 |
| | | G | 74·7†‡ | 2·8 | 1·9 | 30·7 | 8·4 | 5·4 | 1·6 | 13·2 |
| Enkhuizen Glory | CB21 | C4 | 75·0 | 1·6 | 0·7 | 62·5 | 5·6 | 5·2 | 1·1 | 3·3 |
| | | C5 | 72·2 | 2·6 | 1·5 | 43·1 | 6·5 | 6·0 | 1·1 | 7·1 |
| | | G | 70·5 | 3·3 | 2·4 | 28·3 | 8·1 | 7·0 | 1·2 | 15·5 |
| | CB33 | C4 | 48·0 | 1·1 | 0·4 | 60·6 | 4·6 | 4·2 | 1·1 | 1·4 |
| | | C5 | 80·7† | 2·9 | 1·8 | 37·5 | 6·6 | 6·2 | 1·1 | 1·6 |
| | | G | 80·4† | 3·6 | 2·3 | 36·2 | 8·1 | 7·7 | 1·0 | 16·9 |

* C4 = Canberra, July, 1944; C5 = Canberra, Jan., 1945; G = Griffith, July, 1945.
† = Significantly above Canberra, July, 1944, harvest.
‡ = Significantly above Canberra, January, 1945.
(by $t$ test $P < 0.05$)

## 4. The Effect of Strain.

It is well known that the strains within any one variety differ in their capacity to produce marketable heads and in the size and shape of the cabbages produced. The extent of this variation and the importance of growing a highly-productive strain is, however, not so generally realized. The July, 1945, harvest at Griffith may be taken as an example. Five strains of each of five varieties have been chosen to illustrate the magnitude of the differences between strains. The measurements of these strains are shown in Table 3. Included also are the measurements of five strains of the variety Succession, that were grown at Canberra to illustrate the much larger variation between strains of the one variety grown under unfavourable environment conditions.

TABLE 3.—GROWTH RECORDS OF STRAINS OF CABBAGES.

| Variety and Harvest. | Strain. | Origin of Seed. | Marketable Heads. | Head Weight. | | Lost in Stripping. | Average Dimension | | Ratio. Width/Height. | Yield per Acre. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Unstripped. | Stripped. | | Width. | Height. | | |
| | | | % | kg. | kg. | % | in. | in. | | tons |
| Early Jersey .. Wakefield—Griffith, July, 1945, harvest | CB3 | U.S.A. | 80·6 | 1·4 | 0·8 | 47·5 | 4·7 | 7·4 | 0·6 | 5·6 |
| | CB23 | U.S.A. | 84·4 | 1·3 | 0·6 | 51·0 | 4·3 | 7·3 | 0·6 | 4·8 |
| | CB42 | U.S.A. | 87·1 | 1·6 | 0·9 | 45·3 | 5·2 | 8·0 | 0·6 | 6·8 |
| | CB43 | U.S.A. | 96·6 | 1·6 | 0·9 | 40·4 | 4·9 | 7·8 | 0·6 | 8·3 |
| | CB92 | U.S.A. | 95·0 | 1·9 | 0·9 | 53·4 | 5·2 | 7·4 | 0·7 | 7·8 |
| Copenhagen Market—Griffith, July, 1945, harvest | CB7 | U.S.A. | 80·7 | 2·3 | 1·2 | 45·8 | 7·0 | 6·2 | 1·1 | 9·1 |
| | CB11 | U.S.A. | 82·9 | 2·6 | 1·2 | 54·0 | 7·3 | 6·5 | 1·1 | 9·2 |
| | CB37 | U.S.A. | 88·8 | 2·2 | 1·4 | 34·8 | 5·8 | 5·4 | 1·1 | 11·4 |
| | CB72 | U.S.A. | 89·7 | 2·2 | 1·2 | 42·9 | 5·6 | 4·5 | 1·3 | 10·2 |
| | CB123 | Victoria | 86·6 | 2·8 | 1·8 | 35·3 | 6·3 | 5·8 | 1·1 | 14·5 |
| Succession—Griffith, July, 1945, harvest | CB46 | N.S.W. | 55·2 | 3·8 | 2·3 | 38·6 | 9·3 | 6·4 | 1·5 | 11·8 |
| | CB53 | Victoria | 80·0 | 3·5 | 2·4 | 45·5 | 9·2 | 6·1 | 1·5 | 17·7 |
| | CB65 | Unknown | 72·4 | 3·4 | 2·4 | 44·3 | 9·4 | 6·4 | 1·5 | 15·6 |
| | CB101 | Victoria | 79·0 | 2·7 | 1·8 | 34·0 | 8·4 | 5·4 | 1·6 | 13·1 |
| | CB112 | Victoria | 68·4 | 3·6 | 2·4 | 34·3 | 9·1 | 6·3 | 1·4 | 14·9 |
| Enkhuizen Glory—Griffith, July, 1945, harvest | CB19 | U.S.A. | 73·3 | 2·8 | 1·7 | 37·4 | 6·8 | 6·6 | 1·0 | 11·6 |
| | CB24 | U.S.A. | 75·0 | 3·2 | 1·9 | 40·9 | 7·9 | 7·4 | 1·1 | 13·2 |
| | CB75 | U.S.A. | 72·4 | 3·0 | 1·7 | 44·2 | 7·2 | 7·3 | 1·0 | 11·0 |
| | CB109 | Victoria | 83·4 | 3·6 | 2·4 | 35·2 | 7·9 | 6·7 | 1·2 | 18·0 |
| | CB119 | Victoria | 93·5 | 4·3 | 2·9 | 31·5 | 8·8 | 8·1 | 1·1 | 25·1 |
| All Head Early—Griffith, July, 1945, harvest | CB13 | U.S.A. | 65·6 | 3·2 | 2·2 | 32·8 | 8·2 | 6·0 | 1·4 | 13·0 |
| | CB84 | U.S.A. | 73·0 | 2·9 | 1·9 | 34·4 | 8·0 | 6·2 | 1·3 | 12·5 |
| | CB93 | U.S.A. | 75·6 | 3·1 | 2·0 | 36·2 | 8·2 | 6·3 | 1·3 | 13·6 |
| | CB98 | Victoria | 72·1 | 4·0 | 1·9 | 51·4 | 7·9 | 6·8 | 1·2 | 12·7 |
| | CB99 | Victoria | 56·3 | 4·6 | 2·0 | 57·6 | 8·5 | 6·8 | 1·3 | 10·2 |
| Succession—Canberra July, 1944, harvest | CB46 | N.S.W. | 40·0 | 1·5 | 0·5 | 65·8 | 5·3 | 4·2 | 1·3 | 1·3 |
| | CB48 | U.S.A. | 17·4 | 0·7 | 0·3 | 60·6 | 4·5 | 3·3 | 1·4 | 0·3 |
| | CB51 | N.S.W. | 43·6 | 1·8 | 0·5 | 80·6 | 6·2 | 4·3 | 1·5 | 1·5 |
| | CB53 | Victoria | 50·0 | 1·4 | 0·6 | 56·7 | 6·1 | 4·1 | 1·5 | 2·0 |
| | CB59 | U.S.A. | 41·7 | 1·4 | 0·6 | 54·6 | 6·3 | 4·1 | 1·6 | 1·8 |

For example, different strains of the variety Early Jersey Wakefield produced marketable heads ranging from 80 to 95 per cent. of the total heads and the average weight of the stripped heads ranged from 0·6 to 0·9 kilograms. The yields ranged from 5 to 8 tons per acre.

The other varieties showed comparable differences between strains. For Copenhagen Market the average head weights ranged from 1·2 to 1·8 kilograms and the yields from 9 to 14 tons per acre. For Succession the yields ranged from 12 to 18 tons per acre.

Under poorer growth conditions the differences between strains were relatively greater. Thus for Succession, harvested at Canberra in July, 1944, the percentage of marketable heads ranged from 17 to 50, the head weights from 0·3 to 0·6 kilograms, and the yield from 0·3 to 2·0 tons per acre.

## 5. Description of Varieties.

The average growth performances of all the varieties included in the examination of seed lines are listed in Table 4. They are listed in the order in which they matured at Canberra in the summer of 1944-1945. This order is, in general, the order of maturity of the other plantings. There were, however, considerable differences in the times of maturity of different strains of the same variety planted at the same time. As the July harvest at Canberra was unsatisfactory, the figures for this harvest have only been included in the case of two varieties which grew well under these conditions.

Table 4.—Average Growth Performances of Cabbage Varieties at Canberra and at Griffith.

| Variety. | Harvest.* | Number of Strains Examined. | Marketable Heads. | Head Weight. | | Lost in Stripping. | Average Dimensions. | | Ratio, Width/Height. | Yield per Acre. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Unstripped. | Stripped. | | Width. | Height. | | |
| | | | % | kg. | kg. | % | in. | in. | | tons |
| 1. Parisian .. | C | 1 | 68·3 | 3·2 | 1·8 | 43·7 | 5·7 | 3·7 | 1·5 | 8·1 |
| | G | 1 | 92·5 | 1·3 | 0·7 | 47·5 | 6·3 | 4·1 | 1·5 | 5·8 |
| 2. Burrawong .. | C | 1 | 78·3 | 5·7 | 3·7 | 35·1 | 6·2 | 6·2 | 1·0 | 19·0 |
| | G | 1 | 70·4 | 3·7 | 2·6 | 28·9 | 8·2 | 6·9 | 1·2 | 14·9 |
| 3. Glory Resistant Globe | C | 1 | 84·2 | 4·7 | 3·4 | 27·7 | 6·8 | 5·4 | 1·3 | 18·8 |
| | G | 1 | 82·8 | 3·0 | 1·9 | 36·1 | 7·3 | 6·8 | 1·1 | 14·4 |
| 4. Early Jersey Wakefield . | C | 6 | 72·8 | 3·3 | 1·5 | 59·7 | 4·2 | 5·8 | 0·7 | 7·2 |
| | G | 6 | 89·6 | 1·6 | 0·8 | 46·5 | 4·9 | 7·5 | 0·7 | 6·9 |
| 5. Golden Acre .. | C | 6 | 74·1 | 4·7 | 2·7 | 41·7 | 5·5 | 5·7 | 1·0 | 13·1 |
| | G | 7 | 83·6 | 2·4 | 1·6 | 35·7 | 6·9 | 6·4 | 1·1 | 12·0 |
| 6. Copenhagen Market | C | 9 | 68·0 | 4·9 | 2·9 | 40·0 | 6·1 | 5·4 | 1·1 | 13·0 |
| | G | 11 | 83·7 | 2·5 | 1·5 | 40·2 | 7·3 | 6·4 | 1·1 | 11·5 |
| 7. Succession . .. | C | 38 | 80·6 | 4·6 | 3·2 | 42·6 | 7·1 | 4·8 | 1·5 | 16·8 |
| | G | 54 | 71·6 | 3·4 | 2·2 | 34·5 | 9·0 | 6·1 | 1·5 | 14·7 |
| 8. Marion Market .. | C | 7 | 75·8 | 5·8 | 3·4 | 41·5 | 6·0 | 6·0 | 1·0 | 16·9 |
| | G | 7 | 71·8 | 2·9 | 1·6 | 44·6 | 7·4 | 6·9 | 1·1 | 10·8 |

* C = Canberra, Jan., 1945; G = Griffith, July, 1945.

TABLE 4.—(*continued*).

| Variety. | Harvest.* | Number of Strains Examined. | Marketable Heads. | Head Weight. | | Lost in Stripping. | Average Dimensions. | | Ratio. Width/Height. | Yield per Acre |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Unstripped. | Stripped. | | Width. | Height. | | |
| | | | % | kg. | kg. | % | in. | in. | | tons |
| 9. All Seasons .. | C | 4 | 59·3 | 5·8 | 2·8 | 51·7 | 6·5 | 4·7 | 1·4 | 10·9 |
| | G | 4 | 63·0 | 3·6 | 2·2 | 39·0 | 8·4 | 8·8 | 1·3 | 12·7 |
| 10. Enfield Market | C | 1 | 40·9 | 4·1 | 1·6 | 61·0 | 4·8 | 5·4 | 0·9 | 4·3 |
| | G | 1 | 73·0 | 2·9 | 1·3 | 55·4 | 6·4 | 6·7 | 1·0 | 8·8 |
| 11. Irish Cabbage .. | C | 1 | 18·3 | 4·2 | 2·0 | 52·4 | 5·0 | 6·0 | 0·8 | 2·4 |
| | CJ | 1 | 82·1 | 2·8 | 1·7 | 40·4 | 7·1 | 8·6 | 0·8 | 9·1 |
| | G | 1 | 85·7 | 2·7 | 1·7 | 37·3 | 7·1 | 7·2 | 1·0 | 13·6 |
| 12. Enkhuizen Glory | C | 7 | 74·6 | 5·9 | 3·6 | 39·2 | 6·3 | 6·0 | 1·1 | 17·5 |
| | G | 9 | 77·4 | 3·4 | 2·2 | 35·8 | 7·8 | 7·0 | 1·1 | 15·4 |
| 13. Greenleaf Cabbage | C | 1 | 41·7 | 4·0 | 2·2 | 45·0 | 5·0 | 4·2 | 1·2 | 6·0 |
| | CJ | 1 | 91·7 | 2·6 | 1·4 | 45·4 | 7·4 | 7·0 | 0·9 | 8·6 |
| | G | 1 | 52·6 | 2·6 | 1·4 | 45·4 | 7·3 | 6·6 | 1·1 | 6·8 |
| 14 (*a*). Flat Dutch | C | 1 | 41·1 | 5·1 | 2·5 | 53·2 | 6·3 | 4·3 | 1·5 | 6·8 |
| | G | 2 | 36·7 | 3·3 | 1·9 | 42·2 | 8·2 | 5·4 | 1·5 | 6·3 |
| 14 (*b*). Early Flat Dutch | C | 1 | 47·6 | 2·1 | 1·1 | 56·0 | 6·0 | 4·5 | 1·3 | 3·6 |
| | G | 1 | 73·8 | 2·6 | 1·7 | 34·9 | 7·2 | 6·4 | 1·1 | 11·5 |
| 14 (*c*). Late Flat Dutch | G | 1 | 49·3 | 3·4 | 1·9 | 42·7 | 8·4 | 5·9 | 1·4 | 8·7 |
| 15. Southern Glory | C | 1 | 39·0 | 5·8 | 2·7 | 53·4 | 6·2 | 4·8 | 1·3 | 6·9 |
| | G | 1 | 76·6 | 4·3 | 2·5 | 42·0 | 8·6 | 6·6 | 1·3 | 17·7 |
| 16. St. John's Day Select | G | 1 | 65·5 | 4·0 | 2·5 | 32·9 | 8·1 | 6·5 | 1·3 | 15·2 |
| 17 (*a*). Early Drumhead | C | 1 | 63·2 | 6·5 | 3·3 | 49·2 | 6·8 | 5·3 | 1·3 | 13·6 |
| | G | 2 | 55·3 | 3·7 | 3·3 | 39·8 | 8·5 | 6·6 | 1·3 | 16·9 |
| 17 (*b*). Yates' Early Drumhead | C | 1 | 63·8 | 5·2 | 2·6 | 50·0 | 6·4 | 4·3 | 1·5 | 10·8 |
| | G | 1 | 54·6 | 3·3 | 1·9 | 56·2 | 8·9 | 6·3 | 1·4 | 9·4 |
| 17 (*c*). Mammoth Late Drumhead | G | 1 | 54·1 | 3·6 | 2·7 | 26·3 | 9·6 | 6·3 | 1·5 | 13·2 |
| 17 (*d*). Late Type Drumhead | G | 1 | 57·5 | 2·9 | 1·6 | 43·8 | 7·9 | 5·1 | 1·5 | 8·6 |
| 18. Penn State Ballhead | C | 1 | 90·9 | 5·2 | 2·2 | 57·7 | 5·4 | 4·5 | 1·2 | 13·1 |
| | G | 1 | 75·0 | 3·5 | 2·2 | 37·3 | 8·3 | 6·4 | 1·3 | 15·0 |
| 19. All Head Early | C | 5 | 50·0 | 5·6 | 2·7 | 51·4 | 6·1 | 5·2 | 1·2 | 8·9 |
| | G | 5 | 68·5 | 3·5 | 2·0 | 42·4 | 8·2 | 6·4 | 1·3 | 12·4 |
| 20. Huguenot .. | G | 1 | 90·4 | 2·6 | 1·9 | 28·3 | 7·2 | 6·5 | 1·1 | 15·6 |
| 21. Wauchula .. | G | 1 | 76·9 | 2·5 | 1·6 | 33·4 | 6·9 | 6·3 | 1·1 | 11·6 |
| 22. D.N. Savoy .. | G | 1 | 56·2 | 2·7 | 1·1 | 58·9 | 7·1 | 5·9 | 1·2 | 5·9 |
| 23. Drumhead Savoy | G | 1 | 20·6 | 2·5 | 0·8 | 67·0 | 6·6 | 4·9 | 1·4 | 1·6 |

* C = Canberra, Jan., 1945; CJ = Canberra, July, 1945; G = Griffith, July, 1945.

The leading varieties, together with less common varieties with distinctive features are described below. In this description of varieties the ranges in height, width, and weight are the dimensions between which 80 per cent. of the measured heads were recorded.

For example, 80 per cent. of the cabbages of the variety Parisian had heads between 3 and 4 inches high, between 5 and 7 inches wide, and weighed between 1 and 4 lb.

The varieties, in order of maturity at Canberra, January, 1945, are described briefly below:

(1) *Parisian.*—A small flat early cabbage with a high proportion of small firm heads. Light to medium green in colour.

Height—3 to 4 inches. Width—5 to 7 inches.

Weight of stripped cabbage—1 to 4 lb.

(2) *Burrawong.*—An early, medium-sized cabbage. Heads rounded, dull medium green in colour.

Height—5½ to 7½ inches. Width—5½ to 9 inches.

Weight of stripped cabbage—3 to 6½ lb.

(3) *Glory Resistant Globe.*—An early, medium-sized, slightly broad cabbage. Under winter conditions at Canberra 50 per cent. of the heads were marketable. Under warmer conditions during the period of growth 80 per cent. were marketable.

Height—5½ to 7 inches. Width—6 to 8½ inches.

Weight of stripped cabbage—3½ to 6 lb.

Not suitable for growing under cold conditions when the cabbage is maturing.

(4) *Early Jersey Wakefield* (see Figs. 1 and 2).—Synonyms are Early Jersey, Jersey Wakefield, Wakefield, Sugarloaf. The head is small and compact, with a pointed top. The bush is short stemmed and has a wide spread. The colour is a medium dull green—60 to 90 per cent. of the heads are marketable.

Height—5 to 8½ inches. Width 3 to 6½ inches.

Weight of stripped cabbage—1 to 3 lb.

(5) *Golden Acre* (see Figs. 1 and 2).—Synonyms are Earliball, Early Ball, Earliball Golden Acre. A spherical cabbage of early maturity, with short leaves standing well away from the head, which is borne on a stem of medium length. The heads are solid and are not susceptible to splitting, with the inner leaves crisp, tender, and of good flavour. The outer leaves are of a medium green colour. This variety is a selection from Copenhagen Market (described below—variety 6).

Height—4½ to 7½ inches. Width 5 to 8 inches.

Weight of stripped cabbage—1 to 4½ lb.

(6) *Copenhagen Market* (see Figs. 1 and 2).—This variety is similar to Golden Acre except that the stem is somewhat shorter, and the colour of the foliage has a greyish tinge. The head tends to be somewhat egg-shaped in some strains of this variety.

Height—4½ to 7½ inches. Width—5 to 8 inches.

Weight of stripped cabbage—1 to 4½ lb.

(7) *Succession* (see Figs. 1 and 2).—A variety of mid-season maturity. The plant is short stemmed and has a medium to large spread. The outer leaves are medium green in colour. The heads are flat and are considerably wider than high. They tend to split if not harvested soon after reaching maturity.

Under winter conditions at Canberra, only 30 per cent. of the heads were marketable, but this figure was increased to 75 per cent. for the other two plantings.

Height—4 to 7 inches. Width 6 to 10½ inches.
Weight of stripped cabbage—2¼ to 7 lb.

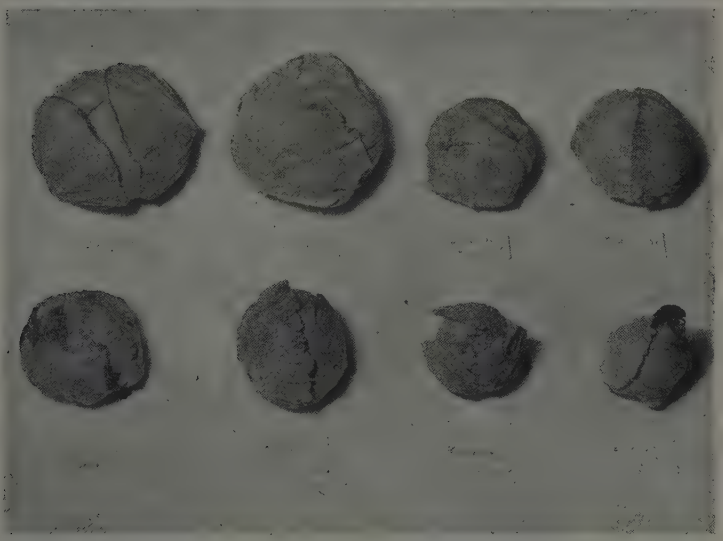


Fig. 1.—The appearance of typical cabbages of seven varieties, after removal of outside leaves.

Top Row.—Succession, All Seasons, Golden Acre (two strains).

Second Row.—Copenhagen Market, Enkhuizen Glory, Huguenot, Early Jersey Wakefield.

(8) *Marion Market*.—A short stemmed cabbage of an erect habit of growth, having a medium spread of leaves. The outer leaves are a medium green in colour. The heads are spherical or slightly egg-shaped at the top.

Height—5½ to 8 inches. Width—5 to 8½ inches.
Weight of stripped cabbage—1½ to 5 lb.

(9) *All Seasons* (see Figs. 1 and 2).—All the seed lines examined were variable in type and matured unevenly. The average plant is vigorous with wide-spreading leaves of a medium green colour. The stem is of medium length and the head well rounded. From 50 to 60

per cent. of the heads were marketable, but the marketable heads did not form a uniform type, their time of reaching maturity being especially variable.

Height—4 to 7½ inches. Width—5½ to 9 inches.

Weight of stripped cabbage—2 to 6 lb.

(10) *Enfield Market.*—A pointed cabbage which is somewhat larger and lighter in colour than Early Jersey Wakefield. The stems are short and the heads split readily if not harvested as soon as mature. The mature plants have a wide spread. This variety produced 30 to 40 per cent. of marketable heads at Canberra and 73 per cent. at Griffith.

Height—4½ to 8 inches. Width—4 to 7½ inches.

Weight of stripped cabbage—1½ to 4½ lb.

(11) *Irish.*—Very similar to Enfield Market, for which the name may be a synonym. The Irish cabbage did not yield satisfactorily as a summer cabbage at Canberra, as in January, 1945, it produced only 18 per cent. of marketable heads and lost 50 per cent. of the total weight in stripping. At the other plantings this variety produced 80 per cent. of marketable heads.

Height—5 to 9½ inches. Width 4½ to 8½ inches.

Weight of stripped cabbage—2½ to 4¾ lb.

(12) *Enkhuizen Glory* (see Figs. 1 and 2).—A mid-season to late cabbage of spherical shape, produced in a large spreading vigorous plant of medium green colour.

Height—5 to 7½ inches. Width 5½ to 8½ inches.

Weight of stripped cabbage—2½ to 6½ lb.

(13) *Greenleaf Cabbage.*—The shiny dark-green colour of the leaves and head is the distinguishing feature of this variety. It is very susceptible to attack by the cabbage aphis (*Aphis brassicae* L.). It is favoured by cold conditions during the period of maturing.

Height—4½ to 7½ inches. Width—5 to 7 inches.

Weight of stripped cabbage—2 to 5 lb.

(14) *Flat Dutch.*—So-called early and late types are included as there were no marked differences in their time of maturity. All were, in fact, late types. The heads of this variety are flattened, the plants being fairly small and the stems short.

Height—4 to 6½ inches. Width—5½ to 9 inches.

Weight of stripped cabbage—1½ to 6½ lb.

(15) *Drumhead types.*—The bushes are large and spreading. The heads are large with flat to dome-shaped tops and borne on short stems.

Height—4 to 7½ inches. Width—6 to 9½ inches.

Weight of stripped cabbage—2 to 6 lb.

(16) *Penn State Ballhead.*—A variety produced at the Pennsylvania Agricultural Experiment Station. This American variety is of very late maturity and does not seem suitable for growing under either

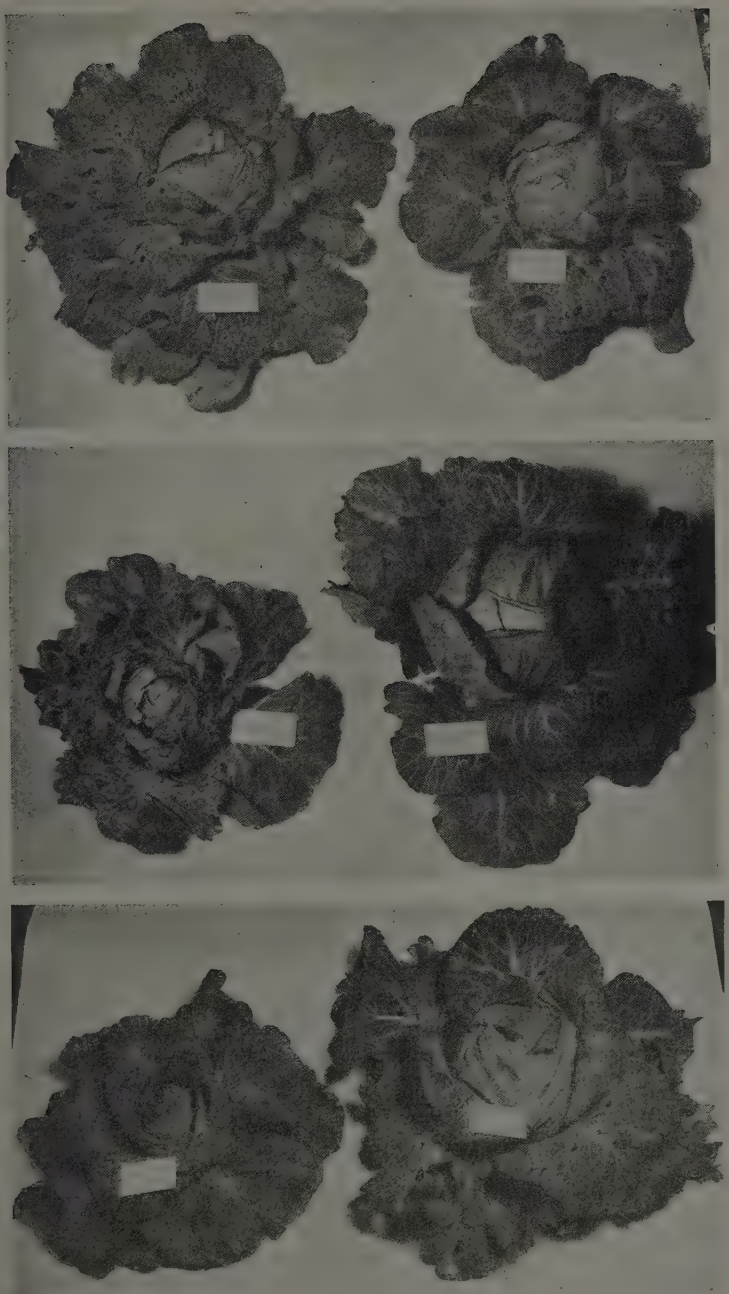


FIG. 2.—The appearance of typical cabbages of six varieties, before removal of outside leaves.

TOP ROW.—Enkhuizen Glory, Copenhagen Market.

SECOND ROW.—Huguenot, Succession.

THIRD ROW.—Early Jersey Wakefield, All Seasons.

Canberra or Griffith conditions. The plants are tall with dull grey leaves. The heads are slightly flattened on top and are borne on long stalks.

Height—4 to 6½ inches. Width—4½ to 9 inches.

Weight of stripped cabbage—1 to 6 lb.

(17) *All Head Early.*—All the seed lines examined were very irregular and poor at both Canberra and Griffith. The most common type was short-stemmed with narrow spreading medium green leaves and a rather flat to dome-shaped head.

Height—4½ to 7½ inches. Width—5½ to 9 inches.

Weight of stripped cabbage—2 to 5½ lb.

(18) *Huguenot, Wauchula, Volnot, and Madison* (see Figs. 1 and 2 for photos of Huguenot).—Conical-headed varieties from the U.S. Regional Vegetable Breeding Laboratory, Charleston, S.C., U.S.A. These are squat, pointed cabbages of very late maturity. The heads arise almost at ground level. The outside leaves are dark green and grow very tightly about the head.

(19) *Savoy types.*—These differ from ordinary cabbages in having their leaves coarsely crimped and of a rich dark-green colour. Two strains were grown but neither was suitable for growing under the conditions of these tests.

## 6. Trends in Commercial Culture.

The variety Succession is at present the most extensively grown in Australia. It is a large, high-yielding cabbage, and its flattened upper surface enables easy stacking on motor trucks for transport. The present trend appears to be for this variety to be replaced by others which have smaller heads and more compact plants. These varieties can be planted at a somewhat closer spacing than Succession. Their yields at closer spacing would be expected to approach that of Succession. The two varieties Golden Acre and Copenhagen Market are of earlier maturity than Succession and the heads are more uniform in size and shape, and show less splitting of heads. The round heads are, however, more difficult to stack for transport than are typical heads of Succession.

## 7. Acknowledgments.

The author wishes to thank Mr. E. S. West, Officer-in-Charge of the Irrigation Research Station, Griffith, and Mr. L. Sharp, Manager of the Dickson Experiment Station, Canberra, for supplying the necessary facilities for the field plots. He also wishes to thank Mr. E. M. Hutton, of the Division of Plant Industry for help with, and advice on, the work. The photographs are the work of Mrs. E. Rankin.

# A Preliminary Report Upon the Cultivation of *Duboisia* Spp.

*By K. Loftus Hills, M.Agr.Sc.,* and G. P. Kelenyi, Dip.Agr.(Dookie)**

*Summary.*

Cultivation experiments with the Australian alkaloid-bearing trees, *Duboisia myoporoides* and *D. Leichhardtii*, are in progress at Nambour, Queensland, and Canberra, A.C.T. The results of the first three years' work are encouraging, and suggest that satisfactory commercial cultivation is possible by a system of repeated cutting, say to about half way down the trees, at intervals as short as three months in sub-tropical environments, and as long as one year in continental climates where growth is slower.

Selection work has revealed the existence of a number of distinct morphological and alkaloid genotypes, and it is hoped that types will ultimately be obtained which carry the alkaloids in a relatively pure form irrespective of environmental conditions. Stable hyoscyamine-bearing lines have already been isolated, although their relative yielding ability is not yet established.

## 1. Introduction

The Australian native species *Duboisia myoporoides* and *D. Leichhardtii* have been developed during recent years as a source of the alkaloids hyoscine and hyoscyamine†. The drugs are extracted from leaves collected from naturally occurring trees. However, the species have a scattered distribution, which makes collection difficult, and the nature of the alkaloids present in such leaf has proved rather variable‡. In view of these and other considerations, it was thought desirable to explore the possibility of cultivating the plants and to determine whether lines or varieties could be selected which would ensure a high content of easily extracted alkaloids of predictable composition. The present paper outlines the progress which has already been made, and indicates the lines along which the investigation is now proceeding.

## 2. Propagation

### (i) *By Seed.*

Initial attempts to germinate the seed proved unsatisfactory. It was found that most seed samples, although they appeared normal, contained a variable proportion of empty or partly-filled seed. The number of full seeds in a series of samples derived from individual trees of both species ranged from nil to 80 per cent., and averaged 13 per cent. The fluctuations did not appear to be related to the geographical origin of the samples or to the year in which the seed was collected. The phenomenon may be due to self sterility, lack of effective pollination, or some other cause, and an explanation is now being sought. However, provided good seed is used, and the temperature is above 60°F., a reasonable seedling emergence is usually obtained

* An officer of the Division of Plant Industry.

† Hyoscyamine yields atropine on racemization.

‡ Loftus Hills, K., Trautner, E. M., and Rodwell, C. N. (1945).—A preliminary report upon variation in the nature and quantity of the main alkaloids in *Duboisia myoporoides* and *Duboisia Leichhardtii*. *J. Coun. Sci. Ind. Res.* (Aust.) 18: 234-53.

within six weeks of sowing. Attempts to speed up germination by a number of dormancy-breaking chemicals have not been successful. However, better germination has been obtained from seed picked whilst the fruits are still green and allowed to ripen indoors than from berries ripened fully on the trees. For example, during the course of an extensive test at Nambour, in which fruits picked at three stages of ripeness were tested at two-monthly intervals over a long period, it was found that the percentage germination of seed from green berries was twice as great as from fully-ripe ones, and that the difference in germination persisted for at least eighteen months.

*Duboisia* seedlings are not particularly sturdy, and grow slowly at low temperatures. For this and other reasons, it is considered desirable to raise them under glass, pricking the seedlings out into flats at 4 in. by 4 in. spacing when they reach the six-leaf stage, and gradually hardening them off in cold frames as transplanting time approaches. The use of sterilized soil is recommended, because damping off often causes substantial losses in the early stages. Red spider has also proved troublesome and regular dusting with finely ground flowers of sulphur is advisable.

(ii) *Vegetative.*

A method of vegetative propagation has already been described*. It is believed that the method is suitable for commercial use, provided it is used by a skilled nurseryman with adequate equipment, including facilities for the maintenance of the necessary high temperatures and humidities. After striking, the cuttings should be transferred to soil containing a high proportion of sand.

### 3. Cultural Methods

(i) *General.*

Preliminary cultivation experiments with both species were commenced at Nambour in south-east Queensland, which has a sub-tropical coastal climate in which *D. myoporoides* thrives naturally, and at Canberra, Australian Capital Territory, which has a continental climate even more extreme than that of the inland area in south-east Queensland that is the natural habitat of *D. Leichhardtii.* Both species seem to prefer deep well-drained red soils, but sufficient exceptions have been encountered, particularly in the case of *D. myoporoides,* to justify the hope that they might be cultivated successfully on a wider range of soil types.

It has been observed that under natural conditions the trees of both species ratooned freely from the stumps after felling, and that partial defoliation was often followed by vigorous re-growth. A basic cultivation experiment was established at Nambour to determine whether this characteristic could be used in practice, and to compare the productivity under several systems of re-cutting with the yield of adult trees. The specific objectives were thus:

(1) to follow the variation in weight of the trees at intervals from seedling stage to maturity;

* Loftus Hills, K. (1945).—A note on vegetative propagation and tree form in *Duboisia* spp. *J. Coun. Sci. Ind. Res.* (Aust.) **18**: 230-233.

(2) to compare the yield of leaf from such trees to that obtained by re-cutting at different frequencies over comparable periods of growth;

(3) to follow the changes in the nature and amount of alkaloids present in the leaves under the several systems of management.

It soon appeared that *D. Leichhardtii* was not well-suited to the Nambour conditions, as a high percentage of the seedlings died, and the growth of the remainder was unsatisfactory. Work with that species was therefore extended at Canberra, where it flourished and was not adversely affected by the 20° or so of frost normally encountered during the winter. However, little growth occurred during the colder six months of the year in the latter environment, and different methods of management were tried in an attempt to overcome the disability.

Although *D. myoporoides* was severely cut back by frost during the winter at Canberra, it made good growth during the summer, and as it was thought possible that economic factors might result in its cultivation in less favourable districts, a number of cultivation trials was established at that centre.

(ii) *The Nambour Experiment.*

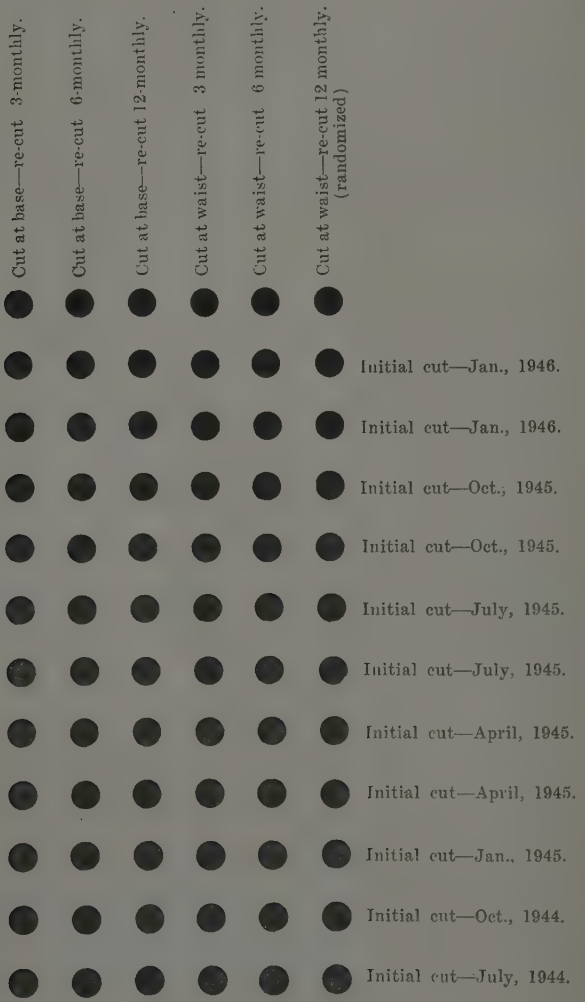
The trial was based upon the following block design, which was replicated six times for each species.

The 72 trees in each block were set 6 feet apart each way in twelve rows of six plants each, the intention being to harvest the twelve rows at successive three-monthly intervals for three years. However, the growth of the trees was so rapid that this was modified after the third harvest, and two rows of six plants were harvested on each subsequent occasion. Thus, the primary cuts concluded after eighteen months. Half of the six (later twelve) trees cut in each block at each harvest were cut at the base to a height of about 12–18 inches from the ground, and the remaining three "lopped" at a point half the height of the tree. The latter will be referred to subsequently as the "waist cut". After each of these cuts, the re-growth was cut back in a similar manner at three, six, and twelve monthly intervals, so that each of the six plants was cut in one of the following ways:—

(1) Cut at the base, re-cut to the base every 3 months.
(2) Cut at the base, re-cut to the base every 6 months.
(3) Cut at the base, re-cut to the base every 12 months.
(4) Cut at the waist, re-cut at the waist every 3 months.
(5) Cut at the waist, re-cut at the waist every 6 months.
(6) Cut at the waist, re-cut at the waist every 12 months.

At each harvest, the individual tree heights and weights were recorded, and estimates of leaf/stem and dry leaf/green leaf ratios made on sub-samples. The leaf samples were kept separate and dried at 105°–115°F. Selected samples were assayed according to the method previously described (Loftus Hills *et al.*, loc. cit.) to ascertain the amount and nature of the main alkaloids present.

The seedlings were transplanted in December, as it was thought that they would established readily at the beginning of the wet season. In fact, they did not do so, initially because of waterlogging of the roots, and subsequently because of short hot dry spells between the summer rains. Transplanting at Nambour in spring is inadvisable because of the limited and unreliable rainfall of that season. Subsequent experience has shown that under these conditions early autumn is probably the best time of the year at which to transplant *Duboisia,* for



if sturdy seedlings at least 12 inches in height are used, they will be large enough by July to withstand the mild frosts expected about that time, and the roots will be sufficiently far down by the spring for the plants to survive the dry periods of spring and early summer.

Seedling losses were severe during the summer following transplanting, and although the early gaps were filled, the position in regard to *D. Leichhardtii* ultimately became so bad that the original experimental plan had to be modified, and the blocks of that species continued mainly on an observational basis. However, three of the six blocks of *D. myoporoides* suffered very few losses, and the remaining three, although variable, were adequate for the principal object of the experiment.

TABLE 1.—THE YIELD FROM YOUNG TREES OF *D. myoporoides* AT SUCCESSIVE AGES FROM SIX MONTHS TO TWO YEARS.

| Age of Trees. | Month of Cut. | Mean Dry Weight of Leaf per Tree. | | Weight of Green Leaf as Percentage of Total Weight of Tree. | Weight of Dry Leaf as Percentage of Weight of Green Leaf. |
|---|---|---|---|---|---|
| | | Entire Tree. | Top Half of Tree. | | |
| months. | | g. | g. | | |
| 6 | July, 1944 .. | 47 | 15 | 56·7 | 33·5 |
| 9 | Oct., ,, .. | 101 | 23 | 53·8 | 29·1 |
| 12 | Jan., 1945 .. | 365 | 193 | 51·9 | 26·9 |
| 15 | Apr., ,, .. | 371 | 145 | 27·5 | 26·5 |
| 18 | July, ,, .. | 165 | 165 | 26·5 | 29·5 |
| 21 | Oct., ,, .. | 278 | 182 | 33·6 | 40·9 |
| 24 | Jan., 1946 .. | 448 | 244 | 27·5 | 27·8 |

The plants did not begin to grow vigorously until the late summer. By May, they had attained an average height of 16 inches. The subsequent increases in the heights of the plants may be followed from the curve in Fig. 1. It will be observed that there was a steady increase until the completion of the "initial cuts" two years after transplanting, and that elongation of the main stem continued through the winter months, at a rate only slightly below that observed during the summer.

The first "initial cut" was made in the July following transplanting, when the seedlings had an average height of 28 inches. By the time of the seventh and final "initial cut" they had reached a height of 150 inches, and appeared as in Fig. 2.

The average yield of air-dry leaf per plant under the base and waist cutting systems may be seen in Table 1, in which the initial cut yields for the experiment are set out. The base cut figures, which represent the yields of dry leaf per tree at three-monthly growth intervals have been plotted in Fig. 1, which also shows the increases in height over the same period. The mean dry weights show a sharp drop during the winter months, which is not accounted for by a corresponding fall in the rate of growth as evidenced by the tree heights. The explanation undoubtedly lies in a fall of leaf which has been observed to take place during the cooler and drier months. It will be seen that the leaf weight rose again as new leaf buds burst in the spring, but the maximum weight reached in the final summer in which initial cuts were made

was only slightly above that recorded in the previous summer. This is not surprising in view of the changes in form which take place as the species mature. The original bushy growth gives way to a typical tree form with a single bare trunk carrying a top canopy of leaves. The two-year-old trees of the Nambour experiment shown in Fig. 2 are typical of the species growing under natural conditions; although under particularly favourable circumstances they may carry more foliage. The yield of dry leaf at the 6 ft. by 6 ft. spacing employed was 1,194 lb. for the two-year period, i.e., at the rate of 597 lb. per acre per annum.

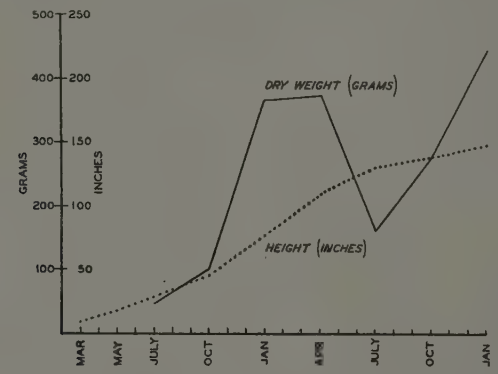



FIG. 1.—The changes in height and in the yield of dry leaf from young trees of *D. myoporoides* at Nambour, Queensland, from 3 to 24 months after transplanting.

As the trees mature, the proportion of green leaf to the total weight of the trees decreases. This can be clearly seen in column 5 of Table 1, which shows the green weights as a percentage of the total tree weights per each harvest. The most important change occurred between twelve and fifteen months after transplanting, when the percentage of green leaf was almost halved. This was possibly accentuated by an autumn leaf fall, but the figures for the following summer indicate that a permanent change in the form of the plant was also involved.

Considerable fluctuation was observed in the percentage of air-dry matter in the leaves, the variation in individual samples in the experiment ranging from 23 to 47 per cent. The mean values at the several times of harvest are shown in column 6 of Table 1. Owing to the unexpectedly high individual tree variations, the population estimates have rather high errors, but there is apparently no consistent relationship between the percentage of dry matter in the leaf and the season of the year.

It is evident that under the conditions of this experiment, the yield of leaf from once-cut plantation-grown trees of *D. myoporoides* reached an economic maximum within fifteen months after transplanting. Although some increase took place in the following summer, it was inadequate to cover the additional costs of tending and rental. Observations of trees growing under natural conditions support these conclusions, and suggest that any subsequent increases in leaf yield would be of a minor nature, except where trees were growing under exceptionally good conditions.

Each of these initial cuts was followed by regular cuts repeated at either 3, 6, or 12 monthly intervals, at the base or waist, according to the nature of the initial cut. The type of cut was found to have a differential effect on mortality. A summary of the figures is given in Table 2, which shows the percentage death rates under the various treatments, up to a period of two years after establishment.

TABLE 2.—THE PERCENTAGE OF DEATHS RESULTING FROM DIFFERENT METHODS OF CUTTING *Duboisia myoporoides*.

| Frequency of Cut. | Percentage of Dead Trees. | |
|---|---|---|
| | Full Cut. | Waist Cut. |
| Every 3 months .. .. .. | 39·4 | 12·1 |
| Every 6 months .. .. .. | 39·4 | 6·1 |
| Every 12 months .. .. .. | 36·4 | 18·2 |
| Mean .. .. .. .. | 38·0 | 12·1 |

FIG. 2.—Two-year-old trees of *D. myoporoides* in the Nambour experiment. These trees have not been cut.

It is clear that frequent cutting has not adversely affected the survival, but there is a substantial difference between the base and waist cut means, the former treatment having resulted in three times the number of deaths as the latter. Observation showed that most of the losses in the base cut series occurred within a few months after the first cut, and that those trees that survived the initial critical period stood up to repeated cutting back as well as did the waist cuts. Dressing of the recently cut stumps with a solution of copper salts was not effective in reducing the mortality.

TABLE 3.—THE YIELD OF LEAF FROM TREES OF *D. myoporoides* SUBJECTED TO DIFFERENT CUTTING TREATMENTS.

| Type of Cut. | * Yield of Air-dry Leaf in Lb. per Acre per Year when Trees Re-cut— | | |
|---|---|---|---|
| | Every Three Months. | Every Six Months. | Every Twelve Months. |
| Base .. .. .. | 558 | 612 | 527 |
| Waist .. .. .. | 1,490 | 1,014 | 703 |

* The yields are calculated on the basis of a full stand, and no allowance has been made for differential mortality.

About 12 per cent. of the waist cut trees were dead after two years. They apparently died at any time subsequent to the cut, and the deaths were not related to either the time of the year at which the initial cut was made or to the age of the tree at the time of the initial cut. The important fact from the practical viewpoint is that the losses sustained by removing at least half the growth from *Duboisia* trees every three months for over two years were not great, and could be replaced quite economically under commercial conditions.

The yield data from such a series of re-cuts are complex, and the interpretation of the results not easy. However, the figures have been reduced to their simplest form in Table 3, which shows the production rates under the different cutting treatments and the yields per acre per year which result. The greatest annual yields have been given by three-monthly waist cuts, and the differential mortality between base and waist cuts serves to accentuate this comparison. The more frequent cutting results in a higher proportion of leaf to stem, but the leaf from the various cutting treatments contains approximately the same percentage of dry matter. The summarized data are shown in Table 4. It is interesting to compare the proportion of leaf in the re-cut samples with those from the initial cuts quoted in Table 1. The three-monthly re-cuts obviously yield a higher proportion of leaf than even six-months-old trees cut for the first time. The individual figures, which are not presented here, show that the high proportion of leaf is maintained even after the seventh re-cut.

The highest yields of the several three-monthly waist cut series were given by the trees cut at an early stage. This is believed to be of some significance, as it is at that stage that the form of the plant will be most influenced by pruning, and the most satisfactory framework

established as a base for subsequent growth. The points at which three successive three-monthly waist cuts were made, and the branching and growth which followed each, can be seen clearly in Fig. 3.

The experiment under discussion was of a preliminary nature, and only two simple alternative types of cut could be included. It was found that the lower lateral branches extended too far horizontally, as may be seen in Fig. 4, which shows a typical three-monthly waist cut tree. However, the dense leafy growth which is typical of re-cut *Duboisia* can be clearly seen. Subsidiary experiments to compare different methods of cutting have shown that a horizontal cut at about one-third of the height of the plant, together with the lopping of the remaining side branches to half their length, is to be preferred.

Table 4.—The Percentage of Leaf from *Duboisia* Trees Subject to Different Systems of Cutting.

| Frequency of Cut. | Green Leaf as Percentage of Total Weight. | | Percentage of Air-dry Matter in Leaf. | |
|---|---|---|---|---|
| | Full Cut. | Waist Cut. | Full Cut. | Waist Cut. |
| 3 months .. .. | 68·3 | 67·0 | 25·6 | 25·9 |
| 6 months .. .. | 55·2 | 63·0 | 23·7 | 26·9 |
| 12 months .. .. | 35·6 | 43·8 | 30·7 | 25·8 |

The chemical work done on material from the Nambour cultivation experiment has so far failed to reveal treatment effects. About 40 samples have been assayed for total alkaloids and the nature of the major alkaloids present, and although some variation is evident there is no general trend. More intensive chemical investigation of the material is planned, and it is possible that treatment differences will emerge as more precise quantitative techniques are employed.

The percentages of total alkaloids in leaf from the initial cuts are shown in Table 5. There is no consistent difference between base and waist cuts, and trees aged from 6 to 24 months do vary greatly in alkaloid content. Table 6 shows the percentage of alkaloids in leaf re-cut at various times after the initial cut made in October, 1944. It is clear that the alkaloid content of the leaves is much the same whether the trees are re-cut at 3, 6, or 12 monthly intervals, and that repeated cutting has not had an adverse effect.

In all cases, hyoscine of varying purity was the main alkaloid present, and neither its purity nor its extractability appear to have been affected by any treatment. The characteristics of the picrates obtained from leaf from an initial cut, from a re-cut three months later, and from the fifth three-monthly re-cut from the same trees are shown in Table 7. It is obvious that the repeated cutting back of these trees has not appreciably affected the nature of the alkaloids. These results are typical, and no evidence has so far been obtained to suggest that repeated and frequent cutting of *Duboisia* trees affects either the amount or nature of the alkaloids in the subsequent leaf growth.

FIG. 3.—Showing the branching growth following successive three-monthly "waist" cuts.

FIG. 4.—A two-year-old tree of *D. myoporoides* in the Nambour experiment, which has been cut back to the waist at three-monthly intervals.

Thus, cultivated *D. myoporoides* has been found to contain large amounts of hyoscine, and the alkaloid complex is very similar to that found in leaf collected from natural stands.

Table 5.—The Total Alkaloid Content of Leaves from Trees of *D. myoporoides* Aged from 6 to 24 Months.

| Age of Tree. | Time of Cut. * | Total Alkaloids. | |
|---|---|---|---|
| | | Full Cut. | Waist Cut. |
| months. | | % | % |
| 6 | July, 1944 .. .. .. | 2·3 | 2·3 |
| 9 | Oct., ,, .. .. .. | 3·8 | 2·8 |
| 12 | Jan., 1945 .. .. .. | 2·9 | 3·2 |
| 15 | April, ,, .. .. .. | 2·0 | 2·3 |
| 18 | July, ,, .. .. .. | 2·8 | 2·5 |
| 21 | Oct., ,, .. .. .. | 2·4 | 2·0 |
| 24 | Jan., 1946 .. .. .. | 2·6 | 2·6 |

Table 6.—The Total Alkaloid Content of Leaves from Trees of *D. myoporoides* Cut Initially in October 1944 and Subjected to Different Re-cutting Treatments.

| Time of Re-cut. | Frequency of Re-cut. | | | | | |
|---|---|---|---|---|---|---|
| | Three-monthly. | | Six-monthly. | | Twelve-monthly. | |
| | Full. | Waist. | Full. | Waist. | Full. | Waist. |
| Jan., 1945 .. | 2·4 | 2·7 | .. | .. | .. | .. |
| April, ,, .. | 2·6 | 2·3 | 2·3 | 2·1 | .. | .. |
| July, ,, .. | 3·1 | 2·5 | .. | .. | .. | .. |
| Oct., ,, .. | 2·8 | 2·7 | 2·4 | 3·0 | 2·9 | 2·4 |
| Jan., 1946 .. | 2·6 | 2·4 | .. | .. | .. | .. |

The data concerning *D. Leichhardtii* have not been discussed. However, the same general trends were observed, good re-growth being maintained under a system of three-monthly re-cuts, and neither the nature nor the quantity of the alkaloids being adversely affected by the treatment. However, hyoscine was the main alkaloid present, and it must be concluded that the conditions prevailing in the Nambour experiment were not satisfactory for the production of hyoscyamine-bearing leaf of *D. Leichhardtii*.

(iii) *Canberra Trials.*

Plots comprising spaced plants of both species were established in Canberra, A.C.T., in the spring of each of the years 1942, 1943, and 1944. It was found that hand watering was necessary just after transplanting, but that once established the seedlings of both species withstood dry conditions very well. Growth was vigorous throughout the summer months, and the trees normally reached a height of 5 feet by the end of April, when growth usually ceased.

Although *D. Leichhardtii* suffered little damage from frost during the winter, *D. myoporoides* was affected to a degree depending upon the severity of the winter and the size of the trees at the end of the growing season. During the first winter after establishment, many of the smaller trees died, and although few deaths were recorded subsequently, frost tipping of the branches was common. However, this tipping and/or the general effect of cold upon the leaf buds had an unexpected effect, in that growth during the following summer was much leafier than that seen in *D. myoporoides* growing in warmer climates. Fig. 5 shows eighteen-months-old trees of *D. myoporoides* at the end of their second summer of uninterrupted growth at Canberra.

FIG. 5.—Eighteen-months-old uncut trees of *D. myoporoides* growing at Canberra. The measuring stick is 6 ft. in length.

TABLE 7.—THE CHARACTER OF THE ALKALOID PICRATES FROM LEAF OF RE-CUT *Duboisia* TREES.

| Treatment. | Hyoscine Fraction. | | | Hyoscyamine Fraction. | | | Residue Fraction. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Amount. | M.P. | Crystal Form. | Amount. | M.P. | Crystal Form. | Amount. | M.P. | Crystal Form. |
| | | °C. | | | °C. | | | °C. | |
| Initial cut (to base) | +++ | 185 | Small needles | ++ | 174 | Prisms and balls | ++ | 182 | Needles |
| 1st re-cut after 3 months | +++ | 185 | Needles | ++ | 181 | Feathery | + | 172 | Balls |
| 5th re-cut after 15 months | +++ | 186 | Needles | + | 181 | Balls and crust | + | 178 | Balls |

Sample trees were cut from the three plots at the end of the second summer of growth, i.e., when fifteen months old. The proportions of green leaf to the total weight of the trees, and of dry leaf to green leaf, were determined for representative types.

The data for the three separate experiments are summarized in Table 8. The yield of dry leaf per acre was of the order of 3,000 lb. per acre for both species. The green leaf comprised about half the total weight of the trees of *D. myoporoides,* and a little more than a third of the weight of *D. Leichhardtii.* The loss of weight by the leaves on drying was variable, ranging from 20 to 39 per cent.

Experiments are in progress to determine which is the best month in which to cut back the trees, and how much foliage can be removed without prejudice to the yield in the following summer. The mortality of *D. myoporoides* during the first winter can possibly be overcome by covering with hessian, &c., and it is believed that this factor should not ultimately prove a deterrent to the cultivation of the species in such an environment.

Although the percentage of total alkaloids in the leaf was much the same at both Canberra and Nambour, there is some evidence that the former environment may favour the formation of hyoscyamine in both species, and the latter, of hyoscine. The *D. Leichhardtii* trees growing at Canberra gave appreciable quantities of hyoscyamine in contrast to the hyoscine of the Nambour trial. However, it is a matter of the balance between the two, and more data are required before a final pronouncement can be made. In the meantime, it is clear that adequate quantities of both alkaloids can be obtained under Canberra conditions.

(iv) *Fertilizers.*

All plantings of *Duboisia* have been liberally fertilized with NPK mixtures, and in the Nambour experiment the trees are given individual dressings every three months. Fertilizer trials are in progress to determine the optimum amounts of such fertilizer, but in the meantime it is safe to apply what, in any particular area, would be considered a liberal dressing of NPK.

Fertilizers have not adversely affected the nature or quantity of the alkaloids, and it appears that any increase in fertility which is followed by increased growth has a favourable effect.

TABLE 8.—THE YIELD OF LEAF OF *Duboisia* SPP AT CANBERRA, A.C.T.

| Year Established. | Species. | Yield of Dry Leaf per Acre.* | Weight of Green Leaf as Percentage of Total Weight. | Weight of Dry Leaf as Percentage of Weight of Green Leaf. |
|---|---|---|---|---|
| | | lb. | | |
| 1943 | *D. myoporoides* .. | 3,958 | 50 | 20 |
| 1943 | *D. Leichhardtii* .. | 2,805 | 36 | 35 |
| 1944 | *D. Leichhardtii* .. | 2,776 | 33 | 39 |
| 1945 | *D. myoporoides* .. | 3,540 | 53 | 25 |
| 1945 | *D. Leichhardtii* .. | 3,839 | 39 | 35 |

* Based on full stands at 4 ft. by 2 ft. spacing.

(v) *Discussion.*

The fact that larger yields of leaf per acre have been obtained at Canberra than at Nambour is explained largely by the wider spacing used at the latter centre. It is believed that the tree density at Nambour could be doubled without seriously decreasing the yield per

tree. However, pests were worse at Nambour, eelworm and various root rots taking a heavy toll, and flea beetles and other insects necessitating frequent sprayings. The only disease of any consequence at Canberra was a bacterial wilt, which caused a low but regular percentage of losses. Land in such a favoured environment as Nambour is expensive, and when account is taken of this and the other factors mentioned, it seems that some area intermediate between the two climatic extremes would probably prove more suitable for the cultivation of *Duboisia* spp. The project is continuing, and pilot plots are to be established in a number of intermediate environments.

### 4. Variation and Selection

(i) *Duboisia myoporoides.*

Three different alkaloid genotypes have been established in this species, and a possible fourth type is now being investigated. Adult trees do not vary greatly in botanical characters, and it is only when the seedling progenies are grown side by side that differences in general form, leaf shape, &c., become evident. Such differences generally accompany differences in the nature or balance of the main alkaloids, although no correlation has been established between morphological characters and the nature of the alkaloids present. The types are separated geographically, but abnormal trees have been located in the same zones and are still being investigated.

The first and commonest type is that found along the eastern Australian coast, from New South Wales to northern Queensland. Hyoscine is usually the only alkaloid present in quantity, although occasionally it may be replaced either wholly or in part by hyoscyamine. Progeny tests indicate that the type is genetically stable for alkaloids, and that any fluctuations which occur are the result of environmental changes, the progenies in such cases behaving in a similar manner to those from other trees of the group.

The second type comprises the southern coastal section of the species, extending from Gosford to the Shoalhaven River in southern New South Wales. Hyoscyamine is usually the only alkaloid present in quantity in either parent or progeny trees*.

The third type has a restricted distribution, at the extreme southern limit of the area in south-eastern Queensland occupied by *D. Leichhardtii*, and in one place the two species occur together. The trees are variable in some botanical characters, such as the length of the lobes of the corolla tubes, but their seedling progenies are very alike in general form and leaf form, and obviously comprise a distinct group. Hyoscine and/or hyoscyamine are found in the parent trees, and a third alkaloid, possibly nor-hyoscyamine, often appears in considerable quantity, and, in one case, to the exclusion of other major alkaloids. This third unidentified alkaloid has appeared in at least one of the seedling progenies.

* Natural stands of this type of *D. myoporoides* have not been used as a commercial source of raw material, because of difficulties encountered in extraction of the alkaloid.

FIG. 6.—Typical seedling tree of the northern type of *D. myoporoides*.

FIG. 7.—Typical seedling tree of the southern type of *D. myoporoides*.

FIG. 8.—Typical seedling tree of the type of *D. myoporoides* occurring at the southern limit of distribution of *D. Leichhardtii*.

FIG. 9.—Typical seedling tree of *D. Leichhardtii*.

The fourth, unconfirmed group, is relatively plentiful in the mountains behind Mullumbimby, in northern New South Wales. The parent trees contain hyoscine and/or hyoscyamine, and occasionally an unknown alkaloid, not nor-hyoscyamine. The progenies of a number of these trees are now being studied.

(ii) *Duboisia Leichhardtii.*

Although considerable variation was observed in the alkaloids from trees comprising natural stands of this species, the seedling progenies do not differ appreciably, although the hyoscine/hyoscyamine ratio varies with the environment in which they are grown. It is apparent that the alkaloids of this species are more susceptible to environmental change than are those of *D. myoporoides.* Considerable variation in the plant form, leaf shape, &c., of individual progenies have been noted, but the variation does not appear to be related to their geographical origin or to the nature of the alkaloids which they contain.

Typical young trees of three types of *D. myoporoides,* and one of *D. Leichhardtii,* are shown in Figs. 6, 7, 8, and 9.

(iii) *Selection of Material for Cultivation.*

A number of individual tree progenies of all types have been established at Canberra and Nambour, with the intention of studying their general agronomic characters, response to cutting back, &c., and the constancy of their alkaloids under the different environments.

The hyoscine-bearing lines do not appear to differ from each other in either the quantity or nature of their alkaloids, and they appear equally responsive to changes in environment. Although the same can be said of the lines of *D. Leichhardtii,* it is apparent that the southern type of *D. myoporoides* yields hyoscyamine under almost any circumstances.

The greatest variation between lines occurs in general plant form and leafiness. These characters are obviously of importance from the point of view of cultivation, and it is proposed to propagate certain hyoscine-bearing lines, which appear superior in these respects, with a view to further yield tests, and possibly later distribution for cultivation.

The first question to settle in regard to hyoscyamine-bearing types is the comparative value of *D. Leichhardtii* and southern *D. myoporoides.* The former is generally a heavier yielder of leaf than the latter, at any rate at Canberra, but more lines of southern *D. myoporoides* are about to be tested in the hope that they will approach *D. Leichhardtii* in yield. In the meantime, a particularly leafy high-yielding type of *D. Leichhardtii* is being propagated for further trials.

The progeny tests discussed above have only been in progress a short time, and certain conclusions may well be modified in later years, particularly as the application of more advanced chemical technique should enable more precise comparisons to be made.

## 5. Conclusion

Although many problems still require solution, and many tentative conclusions require confirmation, it is evident that both species of *Duboisia* can be successfully cultivated, and that yields of dry leaf of the order of 1 ton per acre per annum should be obtained. A hyoscine-bearing type which does not occasionally also yield some hyoscyamine has not yet been discovered, but yield tests of lines which will yield hyoscyamine under almost any conditions are now in progress.

## 6. Acknowledgments

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# Fusarium Wilt of Tomato in Australia.

## 1. The Relationship between Different Isolates of the Pathogen and Resistance in Varieties of *Lycopersicon esculentum* Mill. and other *Lycopersicon* Species.

*By Margaret Mills, B.Sc.,* and E. M. Hutton, M.Sc.†*

*Summary.*

Fusarium wilt of tomatoes causes economic loss in the more northern areas of Australia and on sandy soils in some southern districts. Tomato varieties vary in their degrees of susceptibility to Fusarium wilt under greenhouse conditions. In the field, environmental factors can upset the relative degrees of susceptibility of tomato varieties.

The variety Pan America has been shown to be highly resistant under both greenhouse and field conditions. Lines of *Lycopersicon pimpinellifolium* and one line of *Lycopersicon peruvianum* have also been shown to possess resistance of a high order.

A number of isolates of *Fusarium bulbigenum* var. *lycopersici* have been collected from various tomato-growing areas in Australia. There is evidence that suggests the occurrence of strains among the isolates of Fusarium wilt.

### 1. Introduction.

The northern tomato growing districts of Australia where tropical climatic conditions obtain are subject to Fusarium wilt (*Fusarium bulbigenum* var. *lycopersici* (Brushi) Wr. & R.). From the paper by Aberdeen (1945) on the incidence of the various tomato diseases in Queensland it is evident that Fusarium wilt causes heavy losses in that State every year during the spring and summer months. At Katherine and Adelaide Rivers in the Northern Territory tomato production on army farms during the war was often adversely affected by Fusarium wilt in the main "winter" period, especially in fields that were planted with the crop for two or three consecutive seasons.

In contrast, field culture of tomatoes in the southern part of Australia is not noticeably affected by this disease except in a few well-defined localities. In old market gardens around Sydney it is sometimes economically important. On sandy soils at Mildura in the Murray Valley, at Nelshaby near Port Pirie in South Australia, and along the coast in the Geraldton district (Davenport, 1944) of Western Australia, Fusarium wilt can cause considerable loss in outdoor tomatoes. In greenhouse culture in southern areas Fusarium wilt is often a problem, and soil sterilization or the renewal of soil are ordinary practices to guard against this and other soil-borne diseases.

In two of the largest tomato-growing areas in the Commonwealth, namely, the Murrumbidgee Irrigation Area of New South Wales and the Goulburn Valley of Victoria, Fusarium wilt is not reported as being

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of any importance. This disease has never been recorded as causing losses in Tasmania and in the cooler districts of the mainland.

Fusarium wilt of tomato has been described from most of the warmer tomato-growing areas of the world, but severe losses occur mainly in the more tropical regions. In Australia it is evident that the large, well-established maincrop tomato-growing areas of the south are relatively free from this disease. The areas in southern Australia affected with Fusarium wilt are those providing early tomatoes, and therefore, although relatively small in area, are important. The northern areas which offer the greatest scope for the further development of both early and maincrop tomato growing are those severely affected with Fusarium wilt. It can be concluded that the problem is an important one.

The results reported in this paper concern the degree of resistance or susceptibility possessed by a collection of Australian and overseas tomato varieties to pathogenic isolates of the Fusarium wilt organism from various districts in Australia. In conjunction with this work a small collection of other species of *Lycopersicon* was also tested. An attempt was made to discover whether there were different strains of the Fusarium wilt organism among the various isolates collected.

## 2. Materials and Methods.

Since the variety Bonny Best has been fairly widely grown in Australia, and since it has often been used by overseas workers as a reference variety for Fusarium wilt studies, it has been used throughout the course of this work as a standard for testing the pathogenicity of Fusarium wilt isolates. In Table 1 is given a list of the Fusarium wilt isolates that were pathogenic to Bonny Best, and the districts from which they were obtained. Of the suspected Fusarium wilt isolates used, 33 per cent. were non-pathogenic to Bonny Best and were discarded. Morphological studies of most of these non-pathogenic isolates showed that they were other species of Fusarium.

Table 1.—List of Pathogenic Fusarium Wilt (*Fusarium bulbigenum* var. *lycopersici*) Isolates and the Districts from which Collected.

| | |
|---|---|
| F19 | Hawkesbury College, Richmond, N.S.W. |
| F23 | Brookvale, N.S.W. |
| F33 | Brookvale, N.S.W. |
| F59 | Parramatta, N.S.W. |
| F66 | Parramatta, N.S.W. |
| F92 | Merbein, Victoria. |
| F95 | Stanthorpe, Queensland. |
| F99 | Bendigo, Victoria. |
| F104 | Near Brisbane, Queensland. |
| F105 | Katherine River, Northern Territory. |
| F106 | Adelaide River, Northern Territory. |
| F107 | Hayes Creek, Northern Territory. |

Tomato seedlings for inoculation purposes were raised and treated in the following manner. The seeds were sown in 6-in. pots of steam-sterilized soil. In about 15 days, when the first true leaves were unfolding, the seedlings were pricked out into sterilized flats of soil. After about another 18 days when the 3rd to 4th true leaves were formed, the seedlings were dug up and the soil washed away from the roots with running water. They were then inoculated by dipping the roots into a suspension of macerated mycelium and spores in sterile water. The inoculum used throughout the experiments was prepared according to the method of Wellman (1939).

The isolate of Fusarium wilt to be tested was grown in a petri dish of potato-dextrose-agar for a definite length of time. A disc of this agar culture was removed with a sterile cork borer, ½-in. in diameter, and transferred to a 250 ml. flask containing 100 ml. of modified Tochnai (Wellman, 1939) medium which was prepared as follows: peptone 10·00 g., monopotassium phosphate 0·50 g., magnesium sulphate 0·25 g., dextrose 20·00 g., distilled water 1 litre. 100 ml. of the medium was placed in each of ten 250-ml. flasks and autoclaved for 20 minutes at 15 lb. pressure. The inoculated flasks were incubated at 26°C. for 6 days, when the mycelial mat was removed from the liquid and thoroughly dispersed with an electric stirrer in a small amount of sterile water. The volume of the inoculum was then brought up to 400 ml. with sterile water, and the whole was filtered through cheese cloth to remove any unbroken pieces of mycelium.

Immediately after inoculation the seedlings were planted in 6-in. pots of sterilized soil, five seedlings to a pot. The pots were arranged in a random manner on the bench of a greenhouse and the plants shaded for a few days to help them to recover from the shock of transplanting.

As described in Section 3 most of the varieties initially tested were classified on the basis of the percentage of severely wilted plants present, a month after inoculation. In the later work on varieties and segregating hybrid material, observations on the occurrence of the disease were made by harvesting the plants and rating them both externally and internally for severity of attack of Fusarium wilt.

In Table 2 the 10 classes used for external and internal disease ratings are compared. In spite of a few disparities between the two types of rating, a statistical analysis of the data collected in the second experiment described in Section 5 gave a correlation coefficient of ·91 between the two types of rating. Since the data used for this analysis cover 12 varieties and 10 isolates of the pathogen, the high degree of correlation is a good indication of the accuracy of the rating method. The relation between the internal and external ratings is curvilinear owing to little or no change in the external ratings while the internal ratings increase from 1–4 inclusive. Because of this fact the internal ratings are less liable to error and are to be preferred to external ratings.

With respect to the internal rating method, experiments have shown that the organism is confined to that part of the stem which shows vascular browning. This means that the internal ratings of Table 2 are indicative of the progress of the fungus within tomato plants.

TABLE 2.—DESCRIPTION OF THE TEN DISEASE CLASSES FOR THE EXTERNAL AND INTERNAL RATINGS FOR SEVERITY OF FUSARIUM WILT INFECTION.

EXTERNAL RATING.

| *Class.* | |
|---|---|
| 0 | Healthy. |
| 1 | Cotyledons prematurely shed. |
| 2 | Plant stunted; or lower leaves chlorotic or epinastic. |
| 3 | Lower leaves starting to wilt. |
| 4 | Middle leaves starting to wilt; lower wilted or shed. |
| 5 | Lower and middle leaves wilted; only top leaves unaffected. |
| 6 | All leaves wilting. |
| 7 | All leaves completely wilted. |
| 8 | Leaves dry and dead; stem still turgid and erect. |
| 9 | Top of stem collapsed. |
| 10 | Whole stem collapsed. |

INTERNAL RATING.

| *Class.* | |
|---|---|
| 0 | No browning of vascular tissues. |
| 1 | Vascular browning in tip of tap root. |
| 2 | Vascular browning up to ground level. |
| 3 | Vascular browning advanced to cotyledons. |
| 4 | Vascular browning up to 1st true leaf. |
| 5 | Vascular browning up to second leaf; i.e. about ¼ way up stem. |
| 6 | Vascular browning half way up stem. |
| 7 | Vascular browning three-quarters way up stem. |
| 8 | Vascular browning almost to top. |
| 9 | Vascular browning to top which is still turgid. |
| 10 | Vascular browning to top and breakdown of stem. |

### 3. Susceptibility and Resistance to *Fusarium bulbigenum* var. *lycopersici* among Varieties of *Lycopersicon esculentum*

A collection of tomato varieties from Australian and overseas sources was tested in the greenhouse for resistance to isolates of the Fusarium wilt organism that had been proved highly pathogenic to the variety Bonny Best. At least 24 vigorously growing seedlings of each variety were inoculated as previously described. The varieties were handled in four batches over a period of six months. Several check varieties were included in each batch as a control of the methods used. The behaviour of check varieties varied little from batch to batch.

In Table 3 the varieties tested are grouped on the basis of the percentage of severely wilted plants a month from inoculation.

In Plate 5 are shown varieties representative of the four groups in Table 3.

TABLE 3.—CLASSIFICATION OF TOMATO VARIETIES ON THE BASIS OF PERCENTAGE OF SEVERELY WILTED PLANTS A MONTH AFTER INOCULATION WITH FUSARIUM WILT.

I. Very susceptible varieties giving 100 per cent. or almost 100 per cent. severely wilted plants—

| | | |
|---|---|---|
| Bison | Indiana Baltimore | Stemless Pennorange |
| Bonny Best | Matchless | Stone |
| Cobourg | Red Cap | Tatinter |
| Earliwinner | Rouge de Marmande | Victor |
| Improved Stone | Santa Clara Canner | |

II. Susceptible varieties giving 60–90 per cent. severely wilted plants—

| | | |
|---|---|---|
| Adelaide Dwarf Red | Guernsey Beauty | Ponderosa |
| Australian Large Red | Gulf State Market | Potentate |
| Bonnimar | Hundredfold | Pritchard |
| Bounty | John Baer | Red Marhio |
| Burpee Globe | J.T.D. | San Marzano |
| Burwood Prize | Livingstone Globe | Stemless Pennred |
| Coventry | Michigan State Forcing | Stokesdale |
| Golden Queen | Nystate | Tatura Dwarf Globe |
| Greater Baltimore | Pennheart | Valiant |
| Grosse Lisse | Pink Marhio | Vetomold |

III. Moderately susceptible varieties giving 30–50 per cent. severely wilted plants—

| | | |
|---|---|---|
| Break O' Day | Grothen's Globe | Red Cloud |
| Denisonia | Improved Morse's 133-6 | Riverside |
| Devlin's Choice | Jubilee | Rutgers |
| Earliana | Marglobe | Salads Special |
| Early Chatham | Market King | Sioux |
| Essar | Norton | Table Talk |
| Essary | Pearson | Wanneroo Late |
| Extra Early Harkness | Pearson 29-17 | Wasatch Beauty |
| Garden State | Recruit | Washstate |
| Glostone | | |

IV. Highly resistant variety giving no wilted plants—

Pan America.

Table 3 is interesting in that there appears to be a gradation in susceptibility to Fusarium wilt among tomato varieties. It is possible that the reactions of varieties under different environmental conditions could lead to differing degrees of susceptibility in any one variety. The moderately susceptible group III. contains varieties such as Break O'Day, Pearson, Rutgers, Denisonia, Riverside, and Recruit which have shown good field resistance under the conditions in the Northern Territory and Queensland. From the results in Table 3, it is apparent that Pan America is definitely resistant to Fusarium wilt. This is in accord with the claims of Porte and Walker (1941) who developed this variety. Field observations in Australia, under conditions of widespread Fusarium wilt infection, have confirmed this since no cases of Fusarium wilting have been found in Pan America.

### 4. Susceptibiliy and Resistance to *Fusarium bulbigenum* var. *lycopersici* among Non-Commercial *Lycopersicon* Species.

The resistance of lines of various *Lycopersicon* species was compared in the greenhouse using the varieties Pan America and Bonny Best as controls. The same technique was used as in the variety testing recorded in Section 3 except that all plants were harvested one month from inoculation and ratings were given for both external and internal symptoms of Fusarium wilt.

The results of this test are given in Table 4 and from them it can be seen that the lines of *Lycopersicon pimpinellifolium* are all highly resistant to the isolates of the Fusarium wilt organism used in these experiments. This high degree of resistance is also evident in the Pan America variety developed by Porte and Walker (1941), since one of the parents of this variety is a highly resistant strain of *Lycopersicon pimpinellifolium* discovered by Porte and Wellman (1941).

It is interesting to note the difference in resistance between the two lines of *Lycopersicon peruvianum*, but since it is practically impossible to obtain fertile crosses by ordinary means between *L. peruvianum* and *L. esculentum*, the high resistance to the Fusarium wilt organism of the line shown is of little use for practical breeding purposes. *L. hirsutum* is quite resistant, whereas *L. pissisi* has only a medium degree of resistance to this disease. It is surprising to find that the *Lycopersicon* species cultivated by the natives under tropical conditions in New Guinea is susceptible to Fusarium wilt. From reports received, this New Guinea tomato grows with apparent freedom from disease around native villages.

It can be assumed from these results that most lines of *Lycopersicon pimpinellifolium* are highly resistant to the usual strains of the Fusarium wilt organism found in Australia. Since this species can be crossed easily with ordinary tomato varieties it is the best of the *Lycopersicon* species so far tested as a source of genes conferring a high level of resistance to the organism causing Fusarium wilt in this country. However, it is apparent that Pan America possesses these genes, so that in practical breeding for high resistance to Fusarium wilt under Australian conditions this variety can be used as a source of this valuable character in crosses with susceptible varieties. That the high resistance of Pan America is transferred to the progeny of crosses between it and susceptible varieties has been demonstrated, and will be described in a subsequent paper.

## V. The Possible Occurrence of Strains of *Fusarium bulbigenum* var *lycopersici* of Differing Pathogenicity.

As previously described in Section 2, a number of pathogenic isolates of the Fusarium wilt organism have been obtained from field-grown tomatoes in various localities in Australia. The following experiments were designed to investigate the possibility of variation in pathogenicity of these isolates, i.e. the occurrence of strains of the fungus. At one period during the testing of the susceptibility of varieties to the Fusarium wilt organism described in Section 3, 1,200 plants of 30 different varieties were inoculated to two different isolates of the fungus. Half of the plants of each variety were inoculated with one isolate and half with the other. In Table 5 the relative results obtained from the two isolates are tabulated.

Table 5.—Percentages and Classification of Diseased Plants Resulting from the Use of Two Isolates of the Fusarium Wilt Organism.

| Fusarium Wilt Isolate. | Progressive Total Percentage of Wilted Plants. | | | Non-wilted. |
|---|---|---|---|---|
| | At 20 days. | At 30 days. | At 40 days. | |
| | | | | % |
| F23 | 15 | 35 | 60 | 40 |
| F66 | 22 | 43 | 73 | 27 |

From the results given in Table 5 there is a difference in pathogenicity between these two isolates of Fusarium wilt. In order further to investigate variations in pathogenicity between isolates of

TABLE 4.—SHOWING RESISTANCE OF *Lycopersicon* SPECIES TO *Fusarium bulbigenum* var. *lycopersici*.

| Species | Classification of External Ratings | | | | Classification of Internal Ratings | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | 0's | 1's | 2's to 4's | 5's to 10's | 0's | 1's | 2's to 4's | 5's to 10's | |
| | % | % | % | % | % | % | % | % | |
| *L. hirsutum* .. .. .. | — | 60 | 40 | — | 50 | 45 | 5 | — | Resistant |
| *L. peruvianum* A .. | 40 | 60 | — | — | 100 | — | — | — | Highly resistant |
| *L. peruvianum* B .. .. | 30 | 40 | 30 | — | 20 | 40 | 40 | — | Resistant |
| *L. pimpinellifolium* A .. | 90 | 10 | — | — | 100 | — | — | — | Highly resistant |
| *L. pimpinellifolium* B .. | 100 | — | — | — | 100 | — | — | — | Highly resistant |
| *L. pimpinellifolium* C .. | 95 | 5 | — | — | 100 | — | — | — | Highly resistant |
| *L. pimpinellifolium* D .. | 100 | — | — | — | 100 | — | — | — | Highly resistant |
| *L. pissisi* .. .. .. | 5 | 90 | 5 | — | 40 | 20 | 35 | 5 | Fair resistance |
| *L.* species ex New Guinea .. | — | — | 90 | 10 | — | — | 15 | 85 | Susceptible |
| *L. esculentum* var. Pan America | — | 100 | — | — | 100 | — | — | — | Highly resistant |
| *L. esculentum* var. Bonny Best | — | — | 5 | 95 | — | — | — | 100 | Susceptible |

the organism collected in different localities, an experiment was made in the greenhouse involving 12 tomato varieties and 10 isolates of the Fusarium wilt organism. The experiment was replicated and randomized and 200 plants of each variety were tested, each plant being rated both internally and externally one month after inoculation. The varieties used were Adelaide Dwarf Red, Bonny Best, Break O' Day, Burwood Prize, Earliana, Marglobe, Pan America, Pearson, Pearson 29–17, Rouge de Marmande, Rutgers, and Tatura Dwarf Globe. These varieties represent a range of differing susceptbilities to the Fusarium wilt fungus as shown by the results in Table 6. These figures were calculated by averaging the internal ratings produced by the 10 isolates of the organism, and bear out the previous varietal results discussed in Section 3.

Table 6.—Average Internal Ratings for Fusarium Wilt Development in Twelve Varieties of Tomato.

| Variety. | Average Internal Rating. |
|---|---|
| Bonny Best | 8·27 |
| Rouge de Marmande | 8·26 |
| Adelaide Dwarf Red | 7·55 |
| Burwood Prize | 7·26 |
| Tatura Dwarf Globe | 7·19 |
| Break O' Day | 6·98 |
| Rutgers | 6·98 |
| Earliana | 6·90 |
| Marglobe | 6·16 |
| Pearson | 5·88 |
| Pearson 29-17 | 4·61 |
| Pan America | 0·00 |

In above table minimum difference for significance at 5 per cent. point equals an internal rating of ·91.

In Table 6 Pan America is shown to have outstanding resistance compared with the other varieties. It is interesting to note that Pearson 29–17 is significantly more resistant than Pearson, Marglobe, Rutgers, and Break O' Day. This Pearson selection from Dr. J. E. Knott, University of California, has been shown to possess in addition to this resistance better agronomic characters than Pearson.

In Table 7 the effect of the different isolates on the internal disease ratings of five of the tomato varieties in Table 6 is shown. The varieties were selected to represent fairly well-defined degrees of susceptibility. The Fusarium isolates were selected to cover as wide

a range of districts as possible. Three of the isolates came from the Northern Territory, two from Queensland, three from New South Wales, and two from Victoria.

TABLE 7.—SHOWING EFFECT OF TEN ISOLATES OF THE FUSARIUM WILT ORGANISM ON THE INTERNAL DISEASE RATING OF FIVE SELECTED VARIETIES AND ALSO THE MEAN DIFFERENCES BETWEEN ISOLATES.

| Fusarium Wilt Fungus Strain. | Average Internal Disease Ratings for— | | | | | Average Internal Disease Ratings over These Five Varieties. | Average Internal Disease Ratings over the Twelve Varieties. |
|---|---|---|---|---|---|---|---|
| | Bonny Best. | Adelaide Dwarf Red. | Break O' Day. | Marglobe. | Pearson 29-17. | | |
| F107 | 9·31 | 8·10 | 7·35 | 8·10 | 5·00 | 7·57 | 6·81 |
| F92 | 8·90 | 7·60 | 7·95 | 5·10 | 5·65 | 7·04 | 6·41 |
| F59 | 8·50 | 6·45 | 8·15 | 6·45 | 4·85 | 6·88 | 6·30 |
| F19 | 8·05 | 7·85 | 6·95 | 6·35 | 5·60 | 6·96 | 6·18 |
| F99 | 7·20 | 8·30 | 8·10 | 7·30 | 3·80 | 6·94 | 6·17 |
| F105 | 8·05 | 8·20 | 5·15 | 5·55 | 5·75 | 6·54 | 6·06 |
| F104 | 8·20 | 7·20 | 6·85 | 6·30 | 3·45 | 6·40 | 5·99 |
| F95 | 8·25 | 8·10 | 6·55 | 5·35 | 4·10 | 6·47 | 5·78 |
| F106 | 7·75 | 7·20 | 7·10 | 5·25 | 3·95 | 6·25 | 5·71 |
| F33 | 8·55 | 6·55 | 5·70 | 5·85 | 4·00 | 6·13 | 5·44 |
| Mean of varieties | 8·27 | 7·55 | 6·98 | 6·16 | 4·61 | | |

In Table 7 the differences shown between the mean internal disease ratings resulting from the operation of the various isolates of the Fusarium wilt organism are not statistically significant. However, the average internal disease ratings over the groups of five and twelve varieties for the various isolates show that there is a definite trend towards differences in pathogenicity of the various isolates. That this trend can be more definite when large enough numbers are involved is shown by the results in Table 5 with two isolates.

As a result of this work it can be stated that there is a definite suggestion that under Australian conditions strains exist of the Fusarium wilt fungus with differing pathogenicity. However, it appears that the differences in pathogenicity are not substantial, since it appears difficult to demonstrate such differences. The results in Table 6 show that none of the isolates produced internal browning in plants of the variety Pan America, in fact no isolate so far obtained has been pathogenic to this variety. In Ohio, Alexander and Tucker (1945) have isolated a strain of the Fusarium wilt organism that causes wilting in Pan America, and, therefore, overcomes the high resistance of the root system of this variety as shown by Heinze and Andrus (1945).

## 6. Field Observations on the Incidence of Fusarium Wilt Among Tomato Varieties.

Records of the occurrence of Fusarium wilt among tomato varieties grown in the Red Cliffs plots of the Merbein Research Station have been kept for several years. The soil on which the plots are grown is a red sandy loam and is typical of much of the soil that is used for vegetable growing in this area. As shown in Table 8 there was in the 1943–4 season a fairly high incidence of Fusarium wilt throughout the plots, and in the 1944–5 season the disease was practically absent. In the 1945–6 season there was again a high incidence of Fusarium wilt in the plots.

In Table 8 the incidence of Fusarium wilt for the 1943-4 and 1945-6 seasons among twelve representative varieties is shown.

Table 8.—The Incidence of Fusarium Wilt Infection Among Tomato Varieties Grown in Variety Trials at Red Cliffs.

| Variety. | Wilted Plants in the 1943-4 Season. | Fusarium-affected Plants in the 1945-6 Season. |
|---|---|---|
| | % | % |
| Pan America | Nil | Not recorded |
| Pearson 29-17 | 14 | 39·7 |
| Indiana Baltimore | 17 | 48·8 |
| Marglobe | 19 | Not recorded |
| Rouge de Marmande | 26 | Not recorded |
| Tatura Dwarf Globe | 27 | 42·3 |
| Riverside | 30 | 50·6 |
| Bonny Best | 46 | Not recorded |
| Grosse Lisse | Not recorded | 22·2 |
| Adelaide Dwarf Red | Not recorded | 31·3 |
| Break O' Day | Not recorded | 32·9 |
| Garden State | Not recorded | 54·6 |

Fusarium wilt infection in the 1943–4 season was estimated from counts of completely wilted plants, whereas in the 1945–6 season infection percentages were calculated from the numbers of wilted plants and plants showing basal internal browning at the final harvest. To examine a plant for internal browning, the basal portion was cut open longitudinally with a sharp knife. The higher infection percentages recorded for the 1945–6 season are not due entirely to the different method of estimation of diseased plants.

In the 1945–6 season Pan America was not included in the variety trials at Red Cliffs, but 200 plants were grown in check rows. A study of these plants showed 27·7 per cent. of them to have an internal basal browning. Despite this, these affected plants showed no sign of wilting. Since no internal stem browning of Pan America has been evident in greenhouse disease trials, it is apparent that the question of internal browning under field conditions in relation to the development of the Fusarium wilt organism needs investigation.

From Table 8 it can be seen that Pan America was the most resistant variety in the 1943–4 season, and Bonny Best was the most susceptible. In the 1945–6 season at Red Cliffs, Indiana Baltimore, Riverside, and Garden State were the most susceptible varieties.

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# Observations on the Relative Susceptibility of Potato Varieties to Attack by the Rutherglen Bug (*Nysius vinitor* Berg.)

*By T. Greaves* and R. R. Rochford.†*

*Summary.*

Damage by Rutherglen Bug (*Nysius vinitor* Berg.) to an irrigated experimental potato crop, including 58 different varieties, was recorded by means of a visual rating system. Some varieties were more seriously affected than others; the variety President (Iron Duke) was outstanding in its freedom from attack, and the varieties Rural New Yorker, Scotia, Up-to-Date (Factor), Snowflake, Inverness Favourite, Dunbar Standard, and Early Rose were all damaged to a slight extent only.

Most plants of varieties Warba and Mesaba were killed; and Pontiac, Doon Early, Delaware, Early Triumph, Houma, Great Scot, and Bismark were seriously affected.

Varieties recognized as synonyms showed a similar degree of susceptibility.

A significant reduction in yield was associated with bug damage.

The results from this experimental plot are compared with those from an unirrigated field trial in another locality and this comparison suggests that varieties may differ in relative susceptibility to damage with change of environment.

## 1. Introduction.

The Rutherglen bug, an indigenous Lygaeid, frequently attacks potatoes and other crops in temperate and sub-tropical Australia, causing serious loss in seasons when a lush spring growth is followed by a dry spell. The spring months of September-November, 1945, favoured the development of large populations of the bug on weeds and pastures in the Australian Capital Territory, and when dry conditions set in during December, a serious infestation of vegetable and fruit crops began.

Amongst the vegetable crops affected was a trial planting of potatoes at Dickson Experiment Farm, A.C.T., where a number of varieties, including well established varieties and new crosses, had been planted in a half-acre plot in the alphabetical order of their varietal names. When planting was nearly completed in October, 1945, some additional varieties were received for study, and these were planted in an extension of the plot to the north (Fig. 1). When this plot was invaded by bugs early in December, the opportunity was taken to investigate the relative degree of damage suffered by the different varieties, and surprisingly large differences in susceptibility to attack were revealed.

The number of plants of each variety studied ranged from 7 to 70, but most comprised 20-30 plants. The layout of the plot is shown in Fig. 1 and the length of each varietal block, in the plan, is proportional to the number of plants contained in it. The new crosses are not discussed in the present paper and are represented by blanks in the plan.

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The plants of each variety were planted, as far as possible, in a single row; but some varieties were planted at the end of more than one row to fill in the plot. The rows were 80 yards long and contained 120 plants in each row.

The plot was watered by means of overhead sprinklers every fourteen days in dry periods.

The variety trial plot was flanked on the north, south, and west sides by other potato plots of much greater area, and bugs flying down the prevailing north-north-west wind would have to traverse the surrounding potato plots to reach it.

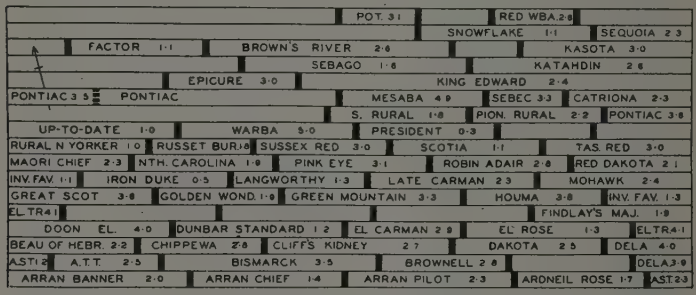


FIG. 1.—Plan of variety trial. Unnamed varietal blocks were occupied by new crosses. Figures represent mean ratings for bug damage.

When the bugs moved into the variety trial, the tips of the favoured plants soon began to wilt, and in early January, 1946, the damage could be readily seen at a distance. Allowing for the inter-variety differences in susceptibility, the attack appeared to be fairly uniform over the plot.

By mid-January, 1946, the varieties Warba and Mesaba had been killed out by the large numbers of bugs which had accumulated on these plants, and varieties Pontiac, Delaware, Doon Early, and Early Triumph were seriously affected.

## 2. Rating of Damage.

A method of rating plants, used for a number of years to provide a quantitative estimate of potato moth damage, has been described by Bald and Helson (1944)*. In assessing the damage by Rutherglen bug, a similar method was employed, i.e. the proportion, either wilted or dried off, was taken as the criterion on which the rating of a plant was based. Ratings used were—

0 = no visible damage by bugs,

1 = up to one-fifth of plant affected,

2 = one-fifth to two-fifths of plant affected,

* Bald, J. G. and Helson, G. A. H. (1944).—Estimation of damage to potato foliage by potato moth (*Gnorimoschema operculella* (Zell.)). *J. Coun. Sci. Ind. Res.* (Aust.) **17**: 30–48.

3 = two-fifths to three-fifths of plant affected,
4 = three-fifths to four-fifths of plant affected,
5 = more than four-fifths affected (such plants are usually dried out).

The number of plants rated for the varieties Pontiac, King Edward, Sebago, Katahdin and Brown's River was limited to the first 30 plants in each varietal block. These varieties had a larger number of plants than the remainder.

Ratings were made on January 25, 1946, and some additional notes on the portion of the plants affected and the density of bug population were made at the same time.

### 3. Results of Ratings and Mean Weight of Tubers.

The mean ratings, the mean yields of tubers per plant in 1946, and the corresponding yields for most of the varieties in 1945, when the plot was virtually free from bug infestation, are given in Table 1.

In comparing the degree of damage, as represented by the ratings, the variety President and its synonym Iron Duke were outstanding in freedom from attack, while the varieties Rural New Yorker, Scotia, Up-to-Date (Factor), Snowflake, Inverness Favourite, Dunbar Standard and Early Rose, all showed slight attack only, and were superior to the remaining varieties.

The most affected of all were two early varieties, Warba and Mesaba, the weak haulms of which were soon killed off by the bugs. Other early and mid-season varieties seriously attacked were Bismark, Delaware, Doon Early, Early Triumph, Great Scot, Green Mountain, Houma, and Pontiac. In general, the late varieties were much less affected than the early and mid-season varieties.

Despite the serious damage to the haulms, the varieties Bismark, Houma, Great Scot, Green Mountain, Delaware, and Pontiac yielded quite good crops. These varieties possessed strong stems which possibly provided food reserves for additional growth to the tubers when the plants died down. Weak plants, such as Doon Early, Early Triumph, Mesaba, and Warba yielded very small crops.

The mean rating of each variety is included in the plan in Fig. 1. It will be seen that the damage along the plot from west-east (as illustrated by the varieties with plants at each end), and the damage across the plot from north-south (as shown by the synonyms occurring across the plot) is very uniform. The recognized synonyms in the plot are: President = Iron Duke; North Carolina = Sequoia; Green Mountain = Early Carman; Brown's River = Tasmanian Red; Up-to-Date = Factor; and Golden Wonder = Langworthy.

The ratings within a variety were fairly uniform, as shown by the frequency distribution figures in Table 1; however, considerable variation occurred in the blocks of Aucklander Short Top and Cliff's Kidney, the variation in the latter was associated with a growth of weeds, overlooked during cultivation, in portion of the row.

TABLE 1.—DETAILS OF BUG DAMAGE AND WEIGHT OF TUBERS HARVESTED.

| Variety. | Frequency Distribution of Ratings. | | | | | | Mean Rating. | Mean Weight of Tubers. (g. per Plant). | | Notes on Damage. |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0. | 1. | 2. | 3. | 4. | 5. | | 1946. | 1945. | |
| Arran Banner .. .. | .. | 2 | 23 | 3 | .. | .. | 2·0 | 733 | 910 | General attack on tips and leaves |
| Arran Chief .. .. | .. | 17 | 6 | 2 | .. | .. | 1·4 | 1,294 | .. | No tip damage, leaves attacked |
| Arran Pilot .. .. | 1 | 1 | 10 | 11 | .. | .. | 2·3 | 1,344 | .. | No tip damage, marginal leaves attacked |
| Ardneil Rose .. .. | 4 | 6 | 5 | 7 | .. | .. | 1·7 | 1,702 | 1,128 | Tips and upper half of plant attacked |
| Aucklander Short Top .. | 2 | 3 | 4 | 2 | 1 | .. | 1·8 | Wt. lost | .. | No tip damage, marginal leaves attacked |
| Aucklander Tall Top .. | .. | 2 | 6 | 10 | 1 | .. | 2·5 | 790 | .. | No tip damage, general attack on leaves |
| Beauty of Hebron .. | .. | .. | 14 | 4 | .. | .. | 2·2 | 985 | 1,215 | No tip damage, general attack on leaves |
| Bismark .. .. | .. | .. | 3 | 11 | 17 | 1 | 3·5 | 1,208 | 2,400 | General attack, many bugs present |
| Brownell .. .. | .. | .. | 4 | 17 | .. | .. | 2·8 | 602 | 2,156 | General concentration of attack on tips |
| Brown's River.. .. | .. | .. | 13 | 17 | .. | .. | 2·6 | 1,352 | 1,732 | General attack, many bugs present |
| Catriona .. .. | .. | 1 | 12 | 8 | .. | .. | 2·3 | 1,676 | .. | Severe tip damage |
| Chippewa .. .. | .. | .. | 7 | 7 | 3 | .. | 2·8 | 874 | .. | General attack |
| Cliffs Kidney .. .. | .. | 4 | 5 | 10 | 3 | 2 | 2·7 | 827 | .. | No tip damage, general attack on leaves |
| Dakota .. .. | .. | .. | 10 | 12 | .. | .. | 2·5 | 1,271 | .. | General attack, many bugs present |
| Delaware .. .. | .. | .. | .. | 2 | 16 | 1 | 3·9 | 494 | 904 | Severe tip damage and general attack |
| Doon Early .. .. | .. | .. | .. | 1 | 22 | 2 | 4·0 | 793 | .. | General attack |
| Dunbar Standard .. | .. | 22 | 4 | .. | .. | .. | 1·2 | 1,149 | .. | No tip damage, margins of lower leaves attacked |
| Early Carman .. | .. | 1 | 3 | 10 | 4 | .. | 2·9 | 1,035 | 959 | General attack |
| Early Rose .. .. | .. | 21 | 2 | 2 | 1 | .. | 1·3 | 1,630 | 2,476 | No tip damage, margins of leaves attacked |
| Early Triumph .. | .. | 1 | 1 | .. | 10 | 4 | 4·1 | 515 | 374 | General attack |
| Epicure .. .. | .. | 1 | 6 | 6 | 9 | .. | 3·0 | 908 | 1,003 | Severe tip and general attack |
| Factor .. .. | 3 | 16 | 3 | 1 | .. | .. | 1·1 | 1,994 | .. | Slight general attack |
| Findlay's Majestic .. | .. | 8 | 11 | 6 | .. | .. | 1·9 | 1,954 | .. | No tip damage, margins of leaves attacked |
| Golden Wonder .. | .. | 3 | 16 | 1 | .. | .. | 1·9 | 1,419 | 924 | Tips and margins of leaves attacked |
| Great Scot .. .. | .. | .. | .. | 8 | 15 | .. | 3·6 | 1,360 | 1,084 | General attack, many bugs present |
| Green Mountain .. | .. | .. | 2 | 15 | 12 | .. | 3·3 | 1,762 | 1,330 | General attack, many bugs present |
| Houma .. .. | .. | .. | .. | 4 | 18 | .. | 3·8 | 1,614 | 773 | Severe tip damage, general attack |
| Inverness Favourite .. | .. | 21 | 5 | .. | .. | .. | 1·2 | 2,418 | .. | Tip damage only |
| Iron Duke .. .. | 12 | 13 | .. | .. | .. | .. | 0·5 | 2,604 | .. | No tip damage, margins of some lower leaves attacked |

TABLE 1.—DETAILS OF BUG DAMAGE AND WEIGHT OF TUBERS HARVESTED—*continued.*

| Variety. | Frequency Distribution of Ratings. | | | | | | Mean Rating. | Mean Weight of Tubers. (g. per Plant). | | Notes on Damage. |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0. | 1. | 2. | 3. | 4. | 5. | | 1946. | 1945. | |
| Kasota | .. | .. | .. | 30 | .. | .. | 3·0 | 999 | 573 | General attack, many bugs present |
| Katahdin | .. | .. | 10 | 19 | .. | .. | 2·7 | 1,315 | 743 | General attack |
| King Edward | .. | .. | 19 | 10 | 1 | .. | 2·4 | 1,004 | 630 | General attack |
| Langworthy | .. | 15 | 8 | .. | .. | .. | 1·3 | 1,323 | 839 | No tip damage, attack on margins of lower leaves only |
| Late Carman | .. | 5 | 9 | 15 | .. | .. | 2·3 | 2,613 | 1,954 | General attack |
| Maori Chief | .. | 2 | 11 | 8 | .. | .. | 2·3 | 1,077 | 701 | General attack |
| Mesaba | .. | .. | .. | 1 | .. | 24 | 4·9 | 650 | 535 | Most plants killed by bugs |
| Mohawk | .. | .. | 17 | 10 | .. | .. | 2·4 | 1,231 | 529 | General attack, many bugs present |
| North Carolina | .. | 4 | 18 | 2 | .. | .. | 1·9 | 2,008 | 2,031 | General attack |
| Pink Eye | .. | .. | .. | 23 | 4 | .. | 3·1 | 654 | 645 | Severe tip damage, general attack |
| Pioneer Rural | .. | 2 | 14 | 7 | .. | .. | 2·2 | 2,005 | 1,012 | General attack |
| Pontiac | .. | .. | .. | 13 | 17 | .. | 3·6 | 1,441 | 903 | Severe tip damage and general attack |
| Potomac | .. | .. | .. | 12 | 1 | .. | 3·1 | 752 | .. | Severe tip damage |
| President | .. | 16 | 8 | .. | .. | .. | 0·3 | 2,120 | 1,762 | No tip damage, margins of some leaves attacked |
| Red Dakota | .. | .. | 18 | 2 | .. | .. | 2·1 | 1,537 | 327 | Tips and upper halves of plants attacked |
| Red Warba | .. | .. | 6 | 8 | .. | .. | 2·6 | 978 | .. | Severe tip and general attack |
| Robin Adair | .. | .. | 6 | 18 | .. | .. | 2·8 | 1,463 | .. | General attack, many bugs present |
| Rural New Yorker | .. | 22 | .. | .. | .. | .. | 1·0 | 1,911 | 834 | No tip damage, margins of older leaves only attacked |
| Russet Burbank | .. | 4 | 12 | .. | .. | .. | 1·8 | 1,329 | 625 | No tip damage, general attack on leaves only |
| Sebago | .. | 13 | 16 | .. | .. | .. | 1·6 | 1,537 | 1,194 | General attack |
| Sebec | .. | .. | 1 | 7 | 5 | .. | 3·3 | 428 | 479 | Severe tip damage and general attack |
| Sequoia | .. | .. | 5 | 2 | .. | .. | 2·3 | 1,147 | 1,633 | General attack |
| Scotia | .. | 21 | 3 | .. | .. | .. | 1·1 | 1,533 | 1,575 | Mainly tip damage |
| Smooth Rural | .. | 5 | 18 | .. | .. | .. | 1·8 | 1,678 | 1,337 | No tip damage, margins of leaves attacked |
| Snowflake | .. | 28 | 1 | 1 | .. | .. | 1·1 | 1,943 | 2,613 | Tip damage only |
| Sussex Red | .. | .. | .. | 20 | 1 | .. | 3·0 | 1,258 | 937 | Severe tip damage, many bugs present |
| Tasmanian Red | .. | .. | .. | 24 | .. | .. | 3·0 | 1,421 | 1,627 | Severe tip damage |
| Up-to-Date | .. | 29 | .. | .. | .. | .. | 1·0 | 1,659 | 2,523 | Slight tip damage |
| Warba | .. | .. | .. | .. | .. | 30 | 5·0 | 542 | 453 | Most plants killed by bugs |

An analysis was made of the data for the 41 varieties for which yields are available for both 1945 and 1946. The inter-correlations of the variety yields in 1945 ($x1$), the variety yields in 1946 ($x2$), and the mean rating of damage ($x3$) were computed as follows:—

$$r_{12} = 0{\cdot}4783$$
$$r_{13} = -0{\cdot}4281$$
$$r_{23} = -0{\cdot}6062$$
$$r_{23{\cdot}1} = -0{\cdot}5058$$

All correlations are significant at the 1 per cent. level. The negative inter-correlation $r_{13}$ may be due to greater relative damage to the varieties with a small amount of foliage, which tend to give lower yields. The partial correlation $r_{23{\cdot}1}$ indicates a significant reduction in yield associated with intensity of bug damage.

### 4. Nature and Extent of Damage to Plant.

The notes in the right hand column of Table 1 show that in the most heavily attacked varieties, both leaves and growing points (tips) were damaged. Plants with low ratings might have—

(*a*) leaf damage only;

(*b*) tip damage only;

(*c*) leaf and tip damage on part only of plant (usually upper shoots); and

(*d*) general, but slight, damage.

It is interesting to note that most varieties with low mean ratings showed leaf damage only, i.e., for some reason or other the tips proved unattractive.

### 5. Comparison Between the Attack on Irrigated and Unirrigated Crops.

One of a series of potato variety trials conducted by the Divisions of Plant Industry and Food Preservation was grown at Bannister, near Crookwell, New South Wales, the fourteen varieties contained in this plot being from the same material as that used at Dickson, A.C.T.

The potatoes were planted in October 1945 and were subjected to severe infestation by Rutherglen bug in December and January, when the bugs migrated from adjacent pasture crops.

The first varieties to be attacked were Aucklander Short Top, Delaware, and Pontiac; and the bugs maintained the attack until these varieties were killed out. The bugs then moved on to the varieties Brownell and Bismark, which were severely affected.

Summer rain fell about this time, and the bugs migrated from the potato plot back to an adjacent crop of subterranean clover; but when this new growth had dried off, the bugs returned to the potatoes and attacked the remaining varieties fairly heavily, without showing any obvious discrimination between them.

The varieties grown at Bannister are listed below, with the mean rating obtained for each in the Dickson, A.C.T., trials given in brackets. The first six varieties are arranged in the order of severity of attack; the last eight, as was indicated above, showed no significant difference from No. 6 (Houma).

| | |
|---|---|
| Aucklander Short Top .. | (1·8) |
| Delaware .. .. | (3·9) |
| Pontiac .. .. | (3·6) |
| Brownell .. .. | (2·8) |
| Bismark .. .. | (3·5) |
| Houma .. .. | (3·8) |
| King Edward .. .. | (2·4) |
| Sebago .. .. | (1·6) |
| Katahdin .. .. | (2·7) |
| Factor .. .. | (1·1) |
| Kasota .. .. | (3·0) |
| Late Carman .. .. | (2·3) |
| Snowflake .. .. | (1·1) |
| Sequoia .. .. | (2·3) |

There are several outstanding anomalies in the results, e.g., the variety Aucklander Short Top, which proved variable but moderately resistant at Dickson, was one of the most heavily attacked varieties at Bannister; and the varieties Houma, Katahdin, and Kasota, which were susceptible to bug attack at Dickson, were included in the less affected varieties at Crookwell. These anomalies suggest that varieties may differ in relative resistance with change in environment.

## 6. Acknowledgments.

The authors wish to acknowledge the assistance given by Mr. G. A. McIntyre in analysing the results, and for suggestions in manner of presentation, and to Dr. J. G. Bald for authoritative information on potato varieties. The observations at Crookwell were made by Mr. J. Flood, on whose property the trial was carried out.

# Fertilizers in Pasture Development on Peat Soils in the Lower South-East of South Australia.

*By A. J. Anderson, B.Sc.(Agric.)**

*Summary.*

Responses of plants to phosphate, copper, zinc, and manganese were obtained in fertilizer trials conducted on peat soils in the lower south-east of South Australia.

There was considerable variation in the mineral dressings required for normal growth of different plant species. Subterranean clover responded to copper and zinc, lucerne responded to copper, *Phalaris tuberosa* responded to zinc, and white clover responded to zinc and manganese. Yorkshire fog did not respond to copper or zinc on soil where subterranean clover responded markedly to both elements. Marked changes in the botanical composition of the pasture resulted from the application of mineral nutrients.

The elements molybdenum, potassium, iron, boron and magnesium had no effect in any of the experiments.

## 1. Introduction.

During recent years it has been found possible to correct low levels of pasture production in an increasing number of localities by the application of one or more of the trace elements essential to plant growth. Experiments of a standard pattern were established in 1942 on a number of soil types in South Australia, to test the effect of mineral nutrients on the yield of pasture. The results obtained on a peat at Rendelsham are included in this paper. Further experiments commenced in 1943 for the Land Board of South Australia, on a peat at Eight Mile Creek, near Port MacDonnell, are also reported in this paper.

Rendelsham and Eight Mile Creek are both situated near the coast in the lower south-east of South Australia. They are within an area receiving an annual rainfall of 25 to 30 inches, most of which falls during the winter months. The soil types and vegetation associations of the Eight Mile Creek area have been described and mapped (Stephens, 1943; Eardley, 1943). The reaction of these peats is described as generally neutral to alkaline, although some faintly acid horizons do occur, particularly in the Badenoch peat.

The peat at Rendelsham has been drained for about 60 years, and at the time of selection the proposed experimental site carried a vigorous stand of Yorkshire fog (*Holcus lanatus* L.). Attempts to establish clovers in pasture on similar adjoining land had been unsuccessful. In contrast, the peat at Eight Mile Creek had been only recently cleared and drained for settlement when work commenced in 1943.

## 2. Experimental.

Leguminous seeds were inoculated with an effective strain of *Rhizobium*, and the seed and fertilizer were hand-broadcast and raked into the soil on plots of 0·0015 acre. Randomization was adopted,

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with the necessary restrictions imposed where blocks or main-plots were included. During preliminary inspections the relative yields of pasture on individual plots were assessed by observation, and the significance of effects of treatments was measured on these assessed values. In all cases where yields are quoted, sample cuts of 12½ square links were made on each plot, and the botanical composition of the pasture was determined by hand-separating representative sub-samples, and weighing the oven-dried material.

(i) *Trials at Rendelsham,* 1942.

The first three trials were sown on May 22, 1942, on a friable peat at Rendelsham. The seeds mixture employed on all plots at this centre consisted of 1 lb. of New Zealand certified white clover (*Trifolium repens* L.) per acre, 1 lb. of Palestine strain of strawberry clover (*T. fragiferum* L.) per acre, 5 lb. of Bacchus Marsh strain of subterranean clover (*T. subterraneum* L.) per acre, 2 lb. of Hunter River strain of lucerne (*Medicago sativa* L.) per acre, 2 lb. of black medic (*M. lupulina* L.) per acre, and 3 lb. of barrel medic (*M. truncatula* Gaertn.) per acre. Thus perennial and annual species of both *Trifolium* and *Medicago* were included. Experiment 1 was harvested on October 31, 1942, and Experiment 3 on December 10, 1942.

Details of the three experiments at Rendelsham are as follows:—

*Experiment* 1.—Designed to test a fertilizer mixture and varying levels of superphosphate. The eight fertilizer treatments were all combinations of—

(*a*) Four levels of superphosphate (22 per cent. $P_2O_5$)—8 cwt., 2 cwt., ½ cwt. per acre, or none.

(*b*) Two levels of a fertilizer mixture—with or without a mixture of 56 lb. of potassium sulphate, 7 lb. of copper sulphate, 7 lb. of zinc sulphate, ¼ lb. of molybdenum trioxide, 7 lb. of ferrous sulphate, 7 lb. of manganese sulphate, 7 lb. of magnesium sulphate, and 3½ lb. of sodium borate per acre.

Basal fertilizer: Nil.

Replications: 2.

*Experiment* 2.—The 32 treatments were all combinations of iron, manganese, magnesium, boron, and a mixture of potassium, copper, zinc, and molybdenum (form and levels as for Experiment 1).

Basal fertilizer: 1½ cwt. superphosphate (22 per cent. $P_2O_5$) per acre.

Replication: 1.

*Experiment* 3.—The 32 treatments were all combinations of potassium, copper, zinc, molybdenum, and a mixture of iron, manganese, magnesium, and boron (molybdenum at 1 lb. molybdenum trioxide per acre or none – form and levels of other nutrients as for Experiment 1).

Basal fertilizer: 1½ cwt. superphosphate (22 per cent. $P_2O_5$) per acre.

Replication: 1.

(ii) *Trials at Eight Mile Creek,* 1943.

Experiments 4, 5, and 6 were sown on October 10, 1943, at Eight Mile Creek, the first two on a friable peat containing abundant calcareous fragments of fresh-water shells, and Experiment 6 on a coarse fibrous peat. The seeds mixture used in these three trials included 1 lb. of *Phalaris tuberosa* per acre in addition to the six leguminous species employed in Experiments 1-3. Seed rates of subterranean clover and barrel medic were reduced to 3 and 2 lb. per acre respectively. Yields of Experiments 4 and 5 were estimated on December 23, 1943, and samples were harvested on February 29, 1944.

Details are as follows:—

*Experiment* 4.—The design of this trial was the same as for Experiment 1, except that molybdenum was used at 2 oz. of molybdenum trioxide per acre.

*Experiment* 5.—The 64 treatments were all combinations of potassium, copper, zinc, manganese, boron, and a mixture of molybdenum, iron, and magnesium (molybdenum at 2 oz. of molybdenum trioxide per acre, or none—form and levels of other nutrients as for Experiment 1).

Basal fertilizer: 2 cwt. superphosphate (22 per cent. $P_2O_5$) per acre.

Replication: 1.

*Experiment* 6.—The treatments potassium, copper, zinc, manganese, and a mixture of iron, boron, magnesium, and molybdenum were tested by omitting each in turn from the fertilizer mixture as used in Experiment 1 (molybdenum was used at 2 oz. of molybdenum trioxide per acre), and comparing these with the complete mixture.

Basal fertilizer: 2 cwt. superphosphate (22 per cent. $P_2O_5$) per acre.

Replication: 1.

(iii) *Trials at Eight Mile Creek,* 1944.

Experiments 7, 8, and 9 were sown at Eight Mile Creek on May 5, 1944, on a soil type classified by Stephens (1943) as the *Badenoch friable peat.* This is described as the most extensive soil of the swamp area. In these three experiments lucerne and annual legumes were excluded from the seeds mixture, which contained only 1 lb. white clover, 1 lb. strawberry clover, and ½ lb. *Phalaris tuberosa* per acre. Samples were harvested on November 5, 1944.

Details are as follows:—

*Experiment* 7.—Designed to test zinc sulphate and varying levels of superphosphate. The sixteen treatments were all combinations of—

(*a*) Two levels of zinc sulphate—7 lb. per acre or none (*main-plots*).

(*b*) Eight levels of superphosphate (18 per cent. $P_2O_5$)—9 cwt., 6 cwt., 4 cwt., 3 cwt., 2⅔ cwt., 2 cwt., 1⅓ cwt., or 8/9 cwt. per acre.

Basal fertilizer: 3½ lb. copper sulphate per acre.

Replications: 4.

*Experiment* 8.—Designed to test zinc sulphate and varying levels of copper sulphate. The ten treatments were all combinations of—

(*a*) Two levels of zinc sulphate—7 lb. per acre or none (*main-plots*).

(*b*) Five levels of copper sulphate—27 lb., 9 lb. 3 lb., 1 lb. per acre, or none.

Basal fertilizer: 2 cwt. superphosphate (18 per cent. $P_2O_5$) per acre.

Replications: 4.

*Experiment* 9.—The 32 treatments were all combinations of zinc, manganese, boron, potassium, and a mixture of molybdenum, iron and magnesium (molybdenum at 1 oz. molybdenum trioxide per acre or none—form and levels of other nutrients as for Experiment 1).

Basal fertilizer: 2 cwt. superphosphate (18 per cent. $P_2O_5$) per acre, and $3\frac{1}{2}$ lb. copper sulphate per acre.

Replication: 1.

### 3. Results.

(i) *Trials at Rendelsham,* 1942.

Clovers sown on peat at Rendelsham had previously failed even when superphosphate had been applied. At this centre, treatment with a mixture of eight nutrients including trace elements (Table 1) increased the yield of subterranean clover (see Plate 3) from 0·17 cwt. per acre to 6·09 cwt. per acre. A similar improvement in the growth of clover was obtained at the same time (Experiment 2) with a mixture of potassium, copper, zinc, and molybdenum.

TABLE 1.—*Experiment* 1: EFFECT OF A MIXTURE OF NUTRIENTS CONTAINING TRACE ELEMENTS, ON THE YIELD OF SUBTERRANEAN CLOVER AND YORKSHIRE FOG. RENDELSHAM, 1942.

(*Dry matter in cwt. per acre.*)

| | Subterranean Clover. | Yorkshire Fog. | Total Yield. |
|---|---|---|---|
| Without trace elements | 0·17 | 9·82 | 9·99 |
| With trace elements | 6·08* | 8·05 | 14·13† |

* Increase significant at $P < 0.01$.
† Increase significant at $P < 0.05$.

Where these four nutrients were tested alone and in combination (Experiment 3), copper and zinc were found to be the only nutrients concerned in the responses obtained. Treatment with a mixture of copper sulphate and zinc sulphate, each at 7 lb. per acre, increased the yield of subterranean clover from 0·99 to 10·73 cwt. per acre (Table 2). Dressings of both copper and zinc were required. In the absence of zinc (Table 2), 7 lb. of copper sulphate per acre increased the yield of subterranean clover from 0·99 cwt. per acre to only 2·96 cwt. per acre; and in the absence of copper, 7 lb. of zinc sulphate per acre had no effect.

Yorkshire fog, which was present on all plots, was particularly vigorous and was not improved by copper or zinc sulphates, or by any other treatment. In experiment 1, which was harvested on October

31, the increase in the yield of subterranean clover with the application of trace elements resulted in an increase in the total yield (Table 1). In Experiment 3 the harvest was not made until December 10, when Yorkshire fog had made its main spring growth. The competition between the subterranean clover and Yorkshire fog was much greater during this later period, and the increase in the yield of subterranean clover resulted only in an increase in the proportion of clover with no increase in the total yield. Strawberry clover did not respond to copper or zinc (Table 2). This may have been due to competition by the other species, particularly as the growth of this perennial species is generally slow in the year of establishment.

TABLE 2.—*Experiment* 3: EFFECT OF COPPER SULPHATE (7 LB. PER ACRE) AND ZINC SULPHATE (7 LB. PER ACRE) ON THE YIELD OF DIFFERENT SPECIES IN A MIXED PASTURE. RENDELSHAM, 1942.

(*Dry matter in cwt. per acre.*)

| | Subterannean Clover. | Strawberry Clover. | Yorkshire Fog. | Total Yield. |
|---|---|---|---|---|
| Nil | 0·99 | 0·39 | 44·9 | 46·3 |
| Zn | 0·67 | 0·39 | 43·5 | 44·5 |
| Cu | 2·96 | 0·53 | 37·6 | 41·1 |
| Zn + Cu | 10·73* | 0·48 | 34·7 | 45·9 |

* The effects of copper and zinc on subterranean clover, and the copper-zinc interaction, were significant at $P < 0·01$.

At Rendelsham, no increase in yield was obtained with nutrients other than copper and zinc. This land had been treated previously with superphosphate, but was stated by the land-holder to have been untreated for about ten years. Prior to this it had received a total of about 5 cwt. of superphosphate per acre with crops of potatoes and rye corn.

(ii) *Trials at Eight Mile Creek,* 1943.

The importance of trace elements and superphosphate in the growth of pasture on the calcareous friable peat at Eight Mile Creek is shown in Table 3. The effects of superphosphate were significant on the yield values estimated in the field, and on the oven-dry yields of harvested material. Where superphosphate was applied alone, the highest yield was obtained with a dressing of 2 cwt. of superphosphate per acre (Table 3). The effect of phosphate was greater in the presence than in the absence of a mixture of other plant nutrients; and in the presence of these nutrients the highest yield was obtained with a dressing of 8 cwt. of superphosphate per acre. The land at Eight Mile Creek had been recently drained and cleared, and had not been treated previously with superphosphate.

TABLE 3.—*Experiment* 4: EFFECT OF SUPERPHOSPHATE AND A MIXTURE CONTAINING TRACE ELEMENTS, ON THE TOTAL YIELD OF PASTURE. EIGHT MILE CREEK, 1943.

(*Dry matter in cwt. per acre.*)

| Superphosphate per Acre. | Without Trace Elements. | With Trace Elements. |
|---|---|---|
| Nil | 9·6 | 15·0 |
| ½ cwt. | 14·3 | 24·4 |
| 2 cwt. | 18·5 | 27·3 |
| 8 cwt. | 15·2 | 30·2 |

Significant difference for P = 0·05 = 10·98.
Significant difference for P = 0·01 = 16·28.

Copper and zinc each increased the total yield on this calcareous peat (Table 4). Yorkshire fog, which was the dominant grass at Rendelsham, was not present on the newly cleared areas at Eight Mile Creek. Here, lucerne and *Phalaris tuberosa* were the dominant species where copper and zinc were applied. The pasture was seeded in the spring, and this, together with the calcareous nature of the soil, favoured the development of lucerne.

TABLE 4.—*Experiment* 5: EFFECT OF COPPER SULPHATE (7 LB. PER ACRE) AND ZINC SULPHATE (7 LB. PER ACRE) ON THE YIELD OF DIFFERENT SPECIES IN A MIXED PASTURE. EIGHT MILE CREEK, 1943.

(*Dry matter in cwt. per acre.*)

| —— | *Phalaris tuberosa.* | Other Non-Legumes. | Lucerne. | Black Medic. | Barrel Medic. | White Clover. | Sub-terranean Clover. | Total Yield. |
|---|---|---|---|---|---|---|---|---|
| Nil .. | 8·5 | 1·7 | 1·9 | 6·1 | 1·6 | 0·19 | 0·01 | 20·0 |
| Zinc .. | 16·1 | 4·3 | 0·9 | 4·0 | 0·8 | 0·15 | 0·08 | 26·3 |
| Copper .. | 8·0 | 1·8 | 16·6 | 4·6 | 3·1 | 0·20 | 0·13 | 34·4 |
| Zinc + Copper .. | 10·5 | 2·6 | 15·9 | 5·1 | 3·1 | 0·34 | 0·16 | 37·7 |
| Treatments significant at P < 0.05 | Copper and inter-action | | | Inter-action | | | | Zinc |
| Treatments significant at P < 0.01 | Zinc | | Copper | | Copper | | | Copper |

Copper markedly increased the yield of lucerne, which assumed dominance on the copper treated pasture (Table 4). The yield of barrel medic also was increased by copper. The increase in the total yield obtained with copper was due mainly to the effect of this element on the lucerne.

The growth of white clover and subterranean clover on this calcareous peat was poor, and the effect of copper on these species was not significant. This may have been due in part to the marked increase in the competitive effect of lucerne resulting from treatment with copper.

The yield of *Phalaris tuberosa* was not increased by copper in any of the trials. The decrease in the yield of Phalaris with the application of copper was apparently due to the marked response by lucerne to this element, and the consequent depression of Phalaris by competition. It is necessary to interpret the results of all these trials in the light of the competitive relations between species of the mixture.

Lucerne and barrel medic did not respond to zinc (Table 4). Whereas copper increased the yield of these species, in the same experiment, 7 lb. of zinc sulphate per acre increased the yield of Phalaris. The increase in the total yield obtained with zinc was due mainly to the effect of zinc on the Phalaris.

Manganese significantly increased the total yield of Experiment 5 estimated in the field ($P < 0{\cdot}05$), but the effect was small and no effect of manganese was obtained on the oven-dry yields of material from a subsequent harvest of this experiment. No increase in yield was obtained with fertilizers other than superphosphate and sulphates of copper, zinc, and manganese.

A marked effect of copper was obtained on lucerne on the coarse fibrous peat (Experiment 6), similar to that obtained in experiments on the calcareous peat. Both effects have persisted strongly for two years (Plate 4, Fig. 1).

(iii) *Trials at Eight Mile Creek*, 1944.

Results obtained on the *Badenoch friable peat* confirm the need for dressings of superphosphate in the development of pasture on the newly-cleared area at Eight Mile Creek (Table 5).

TABLE 5.—*Experiment* 7: EFFECT OF ZINC SULPHATE AND VARYING LEVELS OF SUPERPHOSPHATE ON THE YIELD OF WHITE CLOVER AND *Phalaris tuberosa*. EIGHT MILE CREEK, 1944.

(*Dry matter in cwt. per acre.*)

| Superphosphate per Acre. Cwt. | *Phalaris tuberosa*. | | White Clover. | |
|---|---|---|---|---|
| | Zinc Sulphate per Acre. Nil. | 7 lb. | Zinc Sulphate per Acre. Nil. | 7 lb. |
| 8/9 | 0·31 | 2·74 | 0·35 | 0·37 |
| 1 1/3 | 0·56 | 3·11 | 0·05 | 0·19 |
| 2 | 0·29 | 4·70 | 0·28 | 0·42 |
| 2 2/3 | 0·68 | 3·41 | 0·26 | 0·76 |
| 3 | 0·72 | 4·36 | 0·46 | 0·95 |
| 4 | 1·33 | 5·11 | 0·67 | 2·65 |
| 6 | 1·68 | 3·71 | 0·70 | 1·29 |
| 9 | 2·85 | 3·93 | 3·20 | 3·17 |

TABLE 6.—*Experiment* 8: EFFECT OF ZINC SULPHATE ON THE YIELD OF WHITE CLOVER AND *Phalaris tuberosa*. EIGHT MILE CREEK, 1944.

(*Dry matter in cwt. per acre.*)

| — | White Clover. | *Phalaris tuberosa.* | Other Non-legumes. | Total Yield. |
|---|---|---|---|---|
| Without zinc | 0·24 | 0·51 | 0·16 | 0·91 |
| With 7 lb. zinc sulphate per acre | 0·52* | 3·81* | 0·98 | 5·31* |

* Increase significant at $P < 0·01$.

Manganese significantly increased the yield of white clover on this soil (Table 7). *Phalaris tuberosa* did not respond to manganese, but in the same experiment responded to zinc (Table 7). The importance of zinc on Phalaris can be seen also in Tables 5 and 6, and in Plate 4, Fig. 2. The yield of white clover was also increased by zinc (Table 6).

TABLE 7.—*Experiment* 9: EFFECT OF ZINC SULPHATE (7 LB. PER ACRE) AND MANGANESE SULPHATE (7 LB. PER ACRE) ON THE YIELD OF DIFFERENT SPECIES IN A MIXED PASTURE. EIGHT MILE CREEK, 1944.

(*Dry matter in cwt. per acre.*)

| — | White Clover. | *Phalaris tuberosa.* | Other Non-legumes. | Total Yield. |
|---|---|---|---|---|
| Without manganese | 0·39 | 2·23 | 0·42 | 3·04 |
| With manganese | 1·59* | 2·34 | 0·53 | 4·46 |
| Without zinc | 0·73 | 1·27 | 0·42 | 2·42 |
| With zinc | 1·25 | 3·30* | 0·53 | 5·08* |

* Treatments significant at $P < 0·01$.

Copper did not increase the yield of pasture on this soil, and no increase in yield was obtained with nutrients other than phosphate, zinc, and manganese. However, species responding previously to copper were not included in the seeds mixture.

### 4. Discussion.

The results obtained in the present series of experiments indicate that applications of phosphate, copper, zinc, and manganese may be of benefit on certain species on peat soils in the south-east of South Australia. The elements molybdenum, potassium, iron, boron, and magnesium had no effect in any of the experiments.

Responses to copper, zinc, and manganese have been obtained previously on certain soils in the south-east of South Australia. Samuel and Piper (1928) found that "grey speck" of oats, which occurred on certain alkaline volcanic and black clay soils in the Mount Gambier district, is due to a deficiency of manganese. Dressings of copper are required for the normal growth of certain plants on calcareous soils near the coast (Riceman and Donald, 1938), and "coast disease" of stock, which occurs on untreated land in this area, is due to a dual deficiency of copper and cobalt (Marston *et al.,* 1938). Responses to zinc have also been obtained on this soil (Riceman and Anderson, 1941), and responses to copper have been obtained on a number of other related soils (Riceman and Anderson, 1943).

Benefits have been obtained elsewhere with dressings of trace elements on peat soils. Copper deficiency of plants was first recorded in Europe mainly on acid soils of a peaty nature (Jacks and Scherbatoff, 1934), and Teakle and Morgan (1939) have obtained responses to copper and manganese on peat soils in Western Australia.

In the present work, the responses obtained in factorial experiments emphasize the need for testing nutrients, including trace elements, in combination. In particular, the need for zinc on peat at Rendelsham was evident only where copper was supplied. Both elements need to be applied for normal growth of subterranean clover on this soil. On a nearby property at Rendelsham where clovers had previously failed, a vigorous pasture containing white clover, subterranean clover, and perennial ryegrass has since been established on peat after dressings of copper and zinc were applied.

On a friable calcareous peat at Eight Mile Creek, the response to trace elements increased as the level of phosphate approached the optimum. However, in a trial on *Badenoch friable peat* there was a relatively large effect of the largest dressing of superphosphate when applied without added zinc, and of zinc sulphate applied at lower phosphate levels (Table 5). In this case the effect of superphosphate may have been due in part to zinc contained in this fertilizer. Walkley (1940) has shown that a dressing of 1 cwt. of superphosphate supplies from 1 to 2 oz. of zinc, or an equivalent of $\frac{1}{4}$ to $\frac{1}{2}$ lb. of zinc sulphate per acre.

The marked differences obtained between species in the response to nutrients emphasize the need for including different species in tests with nutrients. Although dressings of both copper and zinc were required for the normal growth of subterranean clover on peat at Rendelsham, neither were required for the normal growth of Yorkshire fog on the same soil. Riceman, Donald, and Evans (1940) and others have shown marked variability in the response of different species to copper. At Eight Mile Creek copper most markedly increased the growth of lucerne, *Phalaris tuberosa* responded most to zinc, and white clover responded to manganese. Consequently marked changes in the botanical composition of the herbage resulted in certain cases from the application of mineral nutrients.

The importance of zinc on *Phalaris tuberosa* may be of particular significance in relation to the occurrence of "Phalaris staggers". This disease of sheep and cattle (McDonald, 1942) is associated with the

ingestion of *Phalaris tuberosa* on certain soils, and McDonald (1946) has recently obtained evidence which suggests that the disease may be prevented by topdressing the pasture with zinc.

The low copper and zinc status of the peat soils studied may possibly reflect a low status of these elements in the basal materials on which the peats were formed. The peat at Eight Mile Creek overlies either highly calcareous sand or polyzoal limestone (Stephens, 1943), and marked copper and zinc deficiencies are known to occur (Riceman and Anderson, 1943) on certain alkaline soils within this region.

## 5. Acknowledgments.

The author is indebted to Mr. S. S. Smith on whose property the experiments at Rendelsham were conducted. The land and facilities necessary for experiments at Eight Mile Creek were made available by the Land Board of South Australia. Thanks are also due to Miss Jean W. Burpee who was responsible for assistance in the technical details associated with the work.

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# Report on the Danish-Seining Trials by the M.V. *Liawenee,* in Southern Tasmanian Waters.

*By Maurice Blackburn, M.Sc.,* and W. S. Fairbridge, M.Sc.**

*Summary.*

A progress report is made upon the Danish-seine fishing tests carried out with the Tasmanian fisheries vessel *Liawenee* over two and a half years in certain waters of that State. The object of the work was to indicate, more clearly than previous efforts had done, what scope existed for commercial fishing of this type in those areas. It is shown that the principal species available is the tiger (king) flathead, which is typically most abundant in the summer and autumn months of the year. The general appraisal of economic potentialities is rendered difficult because of a marked tendency to fluctuation in abundance of flathead on the grounds, in different years at the optimum season, and periods of relative abundance or scarcity at this season may continue for at least two or three years. It is suggested that the possibilities can best be weighed by the members of the fish trade themselves from the detailed data presented, in the light of their individual experience and circumstances.

## 1. Introduction.

The purpose of this paper is to report the results of Danish-seining operations carried out by the Tasmanian State fisheries vessel *Liawenee,* in the south-eastern waters of the State, between February 1944 and July 1946, inclusive.

The *Liawence,* which was commissioned early in 1944, is a wooden craft of the Danish-seiner class (Fig. 1). She is 67 feet long overall, with 18½ feet beam and 8 feet draught, and powered with twin Gardiner 60-h.p. diesel engines. The vessel was built with the purpose of undertaking experimental fishing of different kinds and fisheries research work generally. Although some work was done and is continuing in connexion with pelagic (surface) fish, and a little has been devoted to biological and oceanographical work, the major part of the effort to date has been devoted to Danish-seining in the south-east. This work, with which the Council's Division of Fisheries is very closely associated (as with all other aspects of the vessel's operations), is intended to indicate what commercial prospects exist for demersal (bottom) net fishing in this region. It is still continuing, and the present statement is thus more or less a progress one.

## 2. Results of Previous Surveys.

The only demersal net (or "trawl") fishery which has become in any way established in waters near Tasmania is that which was carried on eastward of Flinders Island by the Sydney steam trawlers prior to their withdrawal during the recent war. This gradually developed, particularly from the early 'thirties onwards, as a southward extension of the operations of these vessels on grounds further north, off the New South Wales and east Victorian coasts. This fishery has probably already been resumed, or soon will be. As is generally known, these grounds (together with many others in various parts of Australia) were first made known as a result of the trawling surveys of the Federal investigation ship *Endeavour* between 1909 and 1913. The *Endeavour* carried out some prospecting in other Tasmanian waters, mostly off

* An officer of the Division of Fisheries.

FIG. 1.—The M.V. *Liawenee*.

(Photo., A. M. Olsen.)

the north-western and south-eastern coasts, but found no grounds as commercially attractive as those at Flinders Island. The best of them was in the Oyster Bay region, where "satisfactory results" were obtained in July and August 1909, but not in the following March (Reports I. and II. of the Director of Fisheries, on Fishing Experiments carried out by the F.I.S. *Endeavour,* to the Parliament of the Commonwealth). However, no great amount of time was devoted to operations in any of these areas, and it cannot be said that they were at all adequately surveyed with the trawl.

A more thorough commercial investigation was made over the period 1937 to 1940 by the Hobart firm of Casimaty Brothers, with their vessel the *Nelson* rigged for Danish-seining. Rather full records of her work have recently been kindly made available by this concern. The *Nelson* spent much of her time prospecting for grounds around the northern and eastern coasts of Tasmania, and even to the vicinity of Strahan on the west coast, but her successful fishing was practically confined to Storm Bay (off Wedge Island) and Marion Bay. Tiger (king) flathead was by far the most important species caught; the quantities of sand flathead, perch (= jackass, morwong, or sea bream of New South Wales), gurnard, flounder, shark, and other fish taken were relatively small. Fishing was continuous, except for one important break of a few months, during the three-year period of operations, and the catches of tiger flathead show an interesting seasonal fluctuation. From November to April in each year production of this species was distinctly higher than for the subsequent six months, perhaps the best period being December to January, when catches were up to about 10,000 to 15,000 lb. for about a week's absence from Hobart.

At the time of her withdrawal from this work in September 1940, the *Nelson* had been for some months experiencing the lean period of the year, and indeed shortage of fish is given as at least one reason for her discontinuing operations in Tasmania and transferring her activities to the New South Wales grounds. It is probable that the war-time dislocation of interstate steamer traffic, which had quite an adverse effect upon fish freights from Hobart to Sydney (then the only market for tiger flathead) in particular, was another difficulty. Whatever the reasons were, the withdrawal of the *Nelson* created the impression, in trade and administrative circles, that the position with respect to the commercial potentialities of the southern Tasmanian trawling grounds was still, to say the least, obscure. It was for this reason that it was decided that this matter should receive special attention from the *Liawenee* as soon as she was commissioned.

### 3. Account of the Work of the *Liawenee*.

Fishing was begun in February 1944, based, as was all subsequent work, on Hobart as home port. At first the grounds off Wedge Island (18 fathoms) seemed the most promising, but they soon gave out, and by the end of the month the vessel had transferred her attention to Marion Bay and was obtaining catches of about 2,000 lb. of flathead a day. This ground received very full attention at all subsequent times, and although later catches here have often been quite low for long periods, no other area was found that could compare with it: it can be said that when fishing was bad generally, Marion Bay (20-35 fathoms) was still better than any other ground worked during these investigations.

From February 1944, fishing was excellent in Marion Bay until the middle of May, when catches began to fall, which they did continually until August. (For a quantitative picture of this and other changes in the rate of catch, see Fig. 2.) Early in May trouble began to be experienced with weed and other bottom rubbish in this area, and this state of affairs must be considered normal for the ground, at least when worked by only one boat, the only months of really clear bottom being

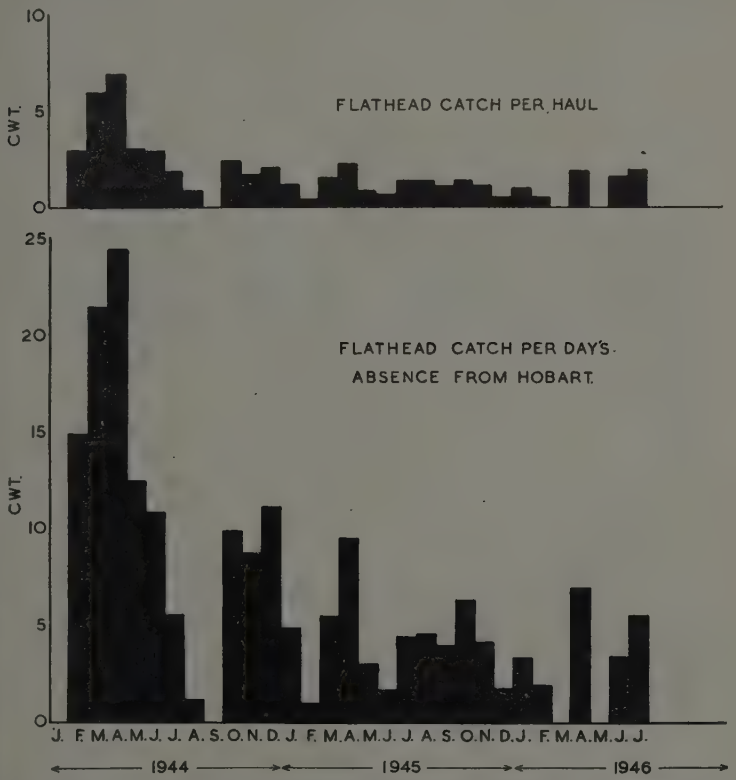


FIG. 2.—Monthly averages of flathead catch, per haul of the Danish-seine and per day's absence from Hobart, obtained by the *Liawenee* on the southern Tasmanian grounds.

from February to May. Throughout the rest of the year great quantities of red, brown, and green weeds, which appear to have broken free and drifted with the currents, are a constant difficulty, together with "pumpkins" and other sponges, and, at times, enormous numbers of spider crabs. Apart from wear and tear on the gear, this makes heavy work for the crew. Some clean bottom is always to be found in this region, but it is often devoid of fish, and since the area of proven fish-carrying bottom is so restricted, the presence or absence of rubbish has an important influence on the success of operations.

During the first six months, and throughout the rest of the period of investigation, the practice was to make one or two shots off Wedge Island whenever possible. This ground is usually quite clear of weed, but only once was really good fishing had there, in November 1944, when about 7,000 lb. of flathead (about half sand flathead, which were spawning) were taken in four days. On the following trip, however, hardly any were found.

When fishing became slack in Marion Bay attention was paid to Oyster Bay, particularly during June and July 1944. The area fished was inside the line of Schouten Island–White Rock–Maria Island, and most of the clear bottom within this area (15-20 fathoms) was worked over. Pumpkins and other sponges and also weed were often troublesome, but during these months the fishing was fair, about as good as in Marion Bay at the same time. Subsequent trials at other times of the year met with no success, often yielding only large bags of weed and rubbish.

When the catches became very low in August 1944, the vessel spent two months in New South Wales, having an echometer fitted in Sydney, and fishing on the south coast trawling grounds. On her return in October she resumed operations in Marion Bay. The fishing showed a distinct improvement, and remained at a moderate level throughout November and December, after which it fell off again for about three months. During this period tests were made in Oyster Bay, in Pirates Bay (40 fathoms), east and north of Maria Island (35-50 fathoms), off Scamander River (20 fathoms), off Wedge Bay, and off Southport. The last named locality (35 fathoms) appeared promising once at the end of January 1945, but subsequent tests in February and May, and again in December, met with no success. Shots were also made from time to time in other parts of Storm Bay besides off Wedge Island, finding always clean bottom, but no fish. From February 1945 onwards, the *Liawenee* began long-line fishing for shark when Danish-seining was slack and there was no other special work (i.e. special research operations) to be done. Flathead became somewhat more plentiful in April, but not nearly as much as at the same time in 1944, and catches soon fell off again and continued to be poor for the remainder of the year. During most of November the vessel was laid up owing to change of skippers. In January and February 1946 considerable time was also devoted to barracouta fishing and the vessel proved good for catching this species. During the autumn of 1946 relatively little use was made of the Danish-seine, as the vessel was being used for work in connexion with pelagic fish. However, such work as was done, in April, and in the following June and July when the effort was considerably increased, revealed a level of abundance much the same as that over the previous two years generally.

No night hauls were made at any time during these experiments.

As is shown in Fig. 3, the Danish-seine caught no great quantity of any fish but flathead, which was always almost exclusively tiger (king) flathead except on the one occasion (November 1944, off Wedge Island) mentioned above. The other fish taken were mainly gurnard, perch, gummy and saw shark, flounder, skate, and cod. Cock gurnards and dogfish were not kept.

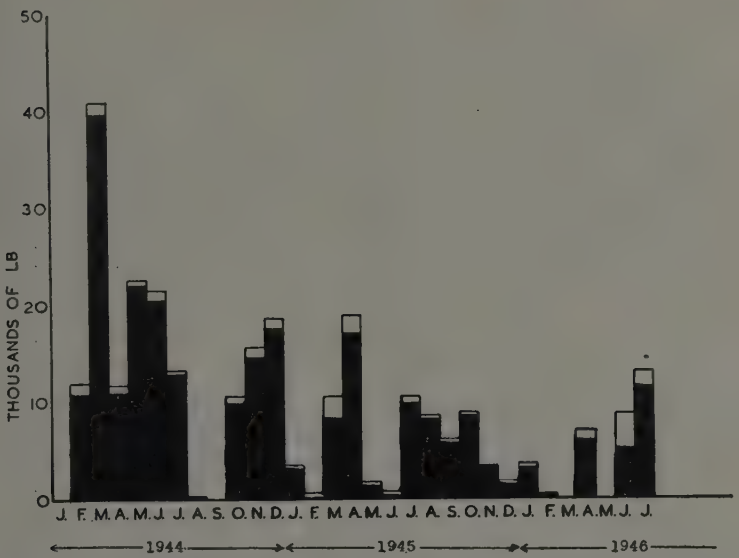


FIG. 3.—Total monthly catches obtained by the *Liawenee* with the Danish-seine on the southern Tasmanian grounds. The darkened parts of the columns indicate flathead, the rest all other fish.

From the beginning of the work until his resignation in November 1945, the vessel was skippered by Captain H. Johnston, who is well known as a successful otter-trawl and Danish-seine fisherman in the New South Wales fishery. For the first six months, Mr. W. Warn, another leading Danish-seine fisherman from New South Wales, was mate. When Mr. Warn resigned, his place was taken by Mr. A. Burnett, at one time skipper of the *Nelson,* who was then mate with Captain Johnston for fifteen months. When Captain Johnston resigned, Mr. Burnett took charge of fishing operations. It can therefore be accepted that the Danish-seining effort of the *Liawenee* has been as efficient as possible at all times, and that any changes in the rate of catch over this period are to be attributed to actual changes in the abundance of catchable fish on the grounds tested.

### 4. Details of Results.

The following table summarizes quantitatively the whole of the Danish-seining work and its results. Most of the essential information is also presented graphically in Figs. 2 and 3.

In explanation of the table, the following points should be noted. Days absent from Hobart are taken to the nearest half-day, i.e., to the nearest 12-hour period, for each cruise; so that if, for example, the vessel left Hobart at 8 a.m. on a Monday and returned at 3 p.m. on the following Friday, the total period of absence, being in all 103 hours, would be taken as 4½ days. Such cruise totals have been added together to obtain a total for each calendar month, including also the odd days in cases where a cruise overlapped the beginning or end of the month.

| Month. | Days Absent from Hobart. | Number of Hauls. | Number of Hauls per Day's Absence. | Flathead. | Other Fish. | All Fish. | Flathead per Day. | Flathead per Haul. |
|---|---|---|---|---|---|---|---|---|
| 1944. | | | | lb. | lb. | lb. | cwt. | cwt. |
| February .. | 6½ | 32 | 5 | 10,871 | 1,067 | 11,938 | 14·9 | 3·0 |
| March .. | 16½ | 60 | 3½ | 39,601 | 1,350 | 40,951 | 21·4 | 5·9 |
| April .. | 4 | 14 | 3½ | 10,897 | 848 | 11,745 | 24·3 | 6·9 |
| May .. | 16 | 63 | 4 | 21,990 | 507 | 22,497 | 12·3 | 3·1 |
| June .. | 17 | 62 | 3½ | 20,462 | 1,178 | 21,640 | 10·8 | 2·9 |
| July .. | 20½ | 60 | 3 | 12,947 | 107 | 13,054 | 5·6 | 1·9 |
| August .. | 2½ | 4 | 1½ | 337 | 4 | 341 | 1·2 | 0·8 |
| September .. | .. | .. | .. | .. | .. | .. | .. | .. |
| October .. | 9 | 38 | 4 | 10,030 | 367 | 10,397 | 9·9 | 2·4 |
| November .. | 15 | 75 | 5 | 14,580 | 1,075 | 15,655 | 8·7 | 1·7 |
| December .. | 14 | 72 | 5 | 17,463 | 1,188 | 18,651 | 11·1 | 2·2 |
| 1945. | | | | | | | | |
| January .. | 6 | 23 | 4 | 3,192 | 302 | 3,494 | 4·8 | 1·2 |
| February .. | 5 | 12 | 2½ | 559 | 186 | 745 | 1·0 | 0·4 |
| March .. | 13 | 46 | 3½ | 8,172 | 2,399 | 10,571 | 5·6 | 1·6 |
| April .. | 16 | 65 | 4 | 16,997 | 1,896 | 18,893 | 9·5 | 2·3 |
| May .. | 4 | 13 | 3 | 1,367 | 383 | 1,750 | 3·1 | 0·9 |
| June .. | 3 | 7 | 2½ | 570 | 96 | 666 | 1·7 | 0·7 |
| July .. | 20 | 62 | 3 | 9,887 | 523 | 10,410 | 4·4 | 1·4 |
| August .. | 16 | 52 | 3 | 8,249 | 252 | 8,501 | 4·6 | 1·4 |
| September .. | 13 | 43 | 3½ | 5,674 | 289 | 5,963 | 3·9 | 1·2 |
| October .. | 12 | 54 | 4½ | 8,531 | 294 | 8,825 | 6·3 | 1·4 |
| November .. | 7 | 25 | 3½ | 3,310 | 48 | 3,358 | 4·2 | 1·2 |
| December .. | 7 | 23 | 3½ | 1,360 | 227 | 1,587 | 1·7 | 0·5 |
| 1946. | | | | | | | | |
| January .. | 8 | 26 | 3 | 2,995 | 485 | 3,480 | 3·3 | 1·0 |
| February .. | 1½ | 5 | 3½ | 306 | .. | 306 | 1·8 | 0·5 |
| March .. | .. | .. | .. | .. | .. | .. | .. | .. |
| April .. | 7½ | 28 | 4 | 5,814 | 940 | 6,754 | 6·9 | 1·9 |
| May .. | .. | .. | .. | .. | .. | .. | .. | .. |
| June .. | 14 | 27 | 2 | 5,114 | 3,643 | 8,757 | 3·3 | 1·7 |
| July .. | 19 | 55 | 3 | 11,697 | 1,460 | 13,157 | 5·5 | 1·9 |

Where a cruise was concerned with other work as well as Danish-seining, the time devoted to the former was estimated as fairly as possible and omitted from the record. The number of hauls includes all except those in which the shot was so spoilt (by the net coming fast, or bursting open, or being so full of weed or mud that the contents had to be released) that no fish were caught; however, some hauls which took some fish in spite of being rather spoilt have been included. The number of hauls per day, to the nearest half, is an average obtained from the previous information. The catch information is straightforward, and the data in the last two columns are flathead catch averages in terms of days and hauls. The quantities of "other fish" may be very slightly on the low side for certain months from February 1945 onwards, since from that date the vessel at times carried out some shark-lining work; and as no distinction was made in the shark catches between those quantities caught in the seine and on hooks, and since the former were usually small, they were disregarded in the Danish-seine catch records.

Of the two flathead catch averages distinguished, the catch per haul is naturally superior as a measure of actual abundance of fish on the grounds, but the catch per day's absence may be more informative from the point of view of the general prospects for commercial operations. Naturally the two series do not run quite parallel, because of time lost in differing degrees at different periods, through bad weather, breakdowns, and other causes; and also because the average number of hauls per day is higher in summer than in winter, owing to the longer daylight hours. The catch per day averages for April, June, and July, 1946, are also slightly low because of refrigerator trouble, which caused the vessel to lose some fishing time through having to make port at Dunalley to unload fish, on many evenings when she could otherwise have remained closer to the grounds overnight.

### 5. General Comment.

It is rather hard to sum up the general position because of the varying nature of the results. Evidently the tiger (king) flathead in these waters is approaching the southern limits of its distribution; the environment is therefore liable to become at times frankly unfavourable to the species, and wide fluctuations in abundance will result. From the work of both the *Liawenee* and particularly the *Nelson*, it appears that the summer and autumn months constitute the best period of the year for flathead, in the years in which there are noticeable differences between seasons. From the *Liawenee's* work it is found that fish were quite abundant at this season in 1943-44, for the part of it that was worked, but only about one-third to one-quarter as plentiful in the two following years at this time, and at other times. The *Nelson* on the other hand found fish much more uniform in abundance from year to year, on the same grounds, at a level comparable with that encountered by the *Liawenee* in her first season, for the three consecutive years in which there was work done at the optimum season, viz. 1937-38, 1938-39, and 1939-40. Obviously the *Liawenee* was unlucky enough to encounter a major fluctuation in the abundance of fish on the grounds, which was probably due to a migratory movement of the flathead. Thus out of the total of six years for which results are available, the catches at the optimum seasons have been pretty uniform at the higher level for four, and uniform at the lower level for two, but since these years were not all consecutive this observation is of rather limited value. Really all that can be said at this stage is that there may be considerable variation in the level of the catch year by year at the optimum season, and that periods of relative abundance or scarcity at this season may continue fairly uniformly for at least two or three consecutive years.

As to the bearing of these results on the question of commercial prospects, it is considered that the possibilities will be best appraised directly by those who may contemplate such fishing in the future, in the light of their own varying experience and circumstances. There seems to be no doubt that the summer and autumn rate of catch in the good years would be quite profitable to most operators, but the position at other times seems to be more marginal, and might appear in a very different light to different potential operators according to the varying cost and efficiency of the vessels and crews they might employ, the different ports from which they might elect to operate (obviously the

catch per day's absence figures given above would have been higher had the *Liawenee* worked from Dunalley or Triabunna rather than Hobart) and the different marketing arrangements they might be able to make. It should be pointed out also that the grounds known to date are rather limited in area, and probably would not support more than a relatively small number of Danish-seiners, although there may be other suitable areas not yet discovered. At any rate, it is hoped that the information presented here will indicate sufficiently good prospects to induce at least a few operators to initiate a commercial Danish-seine fishery in southern Tasmanian waters.

FIG. 4.—Sketch map of Tasmania showing places mentioned in the text, and the approximate boundary of the continental shelf.

## 6. Acknowledgments.

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# The Mechanism of the Oxidant Effects of Commercial Salt and Water in Butterfat.

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*Summary.*

The catalysis of the oxidation of the fat in cold-stored butter by salt and acid present in the water phase was studied by a suitable technique at 40°C. Dispersed water alone in butterfat accelerated oxidation. The mechanism of this acceleration is discussed. Catalysis of fat oxidation by commercial salt in acid solution was found to be due to the combined effects of halide and hydrogen ions. The effect is a direct one between acid salt-solution and fat, the presence of other butter constituents not being necessary. A mechanism for the catalysis is suggested and supported by experimental evidence. It involves the formation by reaction between fat-hydroperoxide and hydrogen and chloride ions, of chlorine, which then activates further oxidation. The previously reported oxidant effect of traces of magnesium chloride in commercial salt, when the salt is dispersed in the dry state in fats and oils, can be similarly explained. Practical implications of these findings are discussed.

## 1. Introduction.

Deterioration of butter in cold-storage is accelerated by high salt content and high acidity. This in practice excludes the highly flavoured high-acid butter from the types which Australia can satisfactorily export, and to that extent restricts the ability of the industry to supply butter suited to particular markets. While the deterioration of cold-stored salted butter made from acid cream has been clearly traced by Wiley (1939) to the acceleration of fat-oxidation, the literature on the oxidation of fats in general does not record or discuss this effect. (The literature dealing with the effect of salt on fat-oxidation was reviewed in an earlier paper (Loftus Hills and Conochie (1945*a*)).

In the studies previously reported it was found that commercial salt when dispersed in the solid state in butterfat exerted a catalytic effect on fat-oxidation. This was found to be due to the traces of magnesium chloride present in the salt. Magnesium chloride was found also to have an oxidant effect when dispersed as an aqueous solution in fat. However, the small amount of magnesium chloride in commercial salt was found to exert a negligible effect on oxidation when solutions of commercial salt were dispersed in butterfat, and it was not possible to account in this way for the oxidant action of commercial salt in acid butters. It seemed likely that a new form of catalysis of fat-oxidation was involved in this activity of acid and salt, and experimental investigation of the mechanism of the effect was undertaken.

In the oxidation of edible fats, the series of reactions which follows the initial combination with oxygen, and results ultimately in the formation of products with objectionable flavour, occurs more readily than the initial oxidation. The acceleration of oxidative fat-deterioration may therefore be explained by any mechanism which accounts for more rapid interaction of fat and oxygen to form fat hydroperoxide.

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## 2. Experimental Methods.

The slow rate of oxidation of the fat of butter in cold storage at —10°C. makes experimental study at such temperatures most inconvenient. If butter is held at temperatures above 0°C. bacterial activity interferes with the oxidation of the fat. Above about 33°C. melting of the fat and separation of the phases takes place. To make use of higher temperatures in obtaining results more rapidly it was necessary to modify the technique previously used in studying the effect of dispersed phases on the oxidation of butterfat at 40°C. (Loftus Hills and Conochie, 1945*a*). A higher percentage of fully hydrogenated peanut oil was added to give greater solidity to the fat at 40°C., and so maintain the necessary fine moisture distribution; and the samples were pasteurized at one stage of their preparation in order to minimize microbiological activity. During incubation the jars were kept tightly stoppered to prevent evaporation of water. Sufficient oxygen for the required degree of oxidation was present dissolved in the fat, and in the headspace gas.

Freshly churned unworked butter granules were melted and heated with constant stirring to 80°C. for 1 minute. The melted butter was then cooled to 65°C. and the serum allowed to settle from the fat. Any necessary additions of sterile salt or acid were then made, and 10 per cent. of fully hydrogenated peanut oil was melted and added to the fat. The butter was reconstituted by stirring during hardening in an ice-water bath, and then incubated at 40°C. for 8–14 days. At the end of the incubation period the butters showed bacterial counts of the order of 100,000 per ml., mostly spore-forming organisms, but the oxidation values for the fats shown in Table 1 demonstrated that it was possible with this method to reproduce rapidly at 40°C. the acceleration of fat-oxidation by acid and salt known to take place in butter over long periods in cold-storage. As in cold-storage, neither salt nor acid alone greatly accelerated oxidation, but the combined effect was considerable.

Even more useful was the demonstration that pure butterfat obtained from the same butter granules and with a dispersed synthetic inorganic butter-serum showed the same effect to a more marked degree, thus providing a simple means for rapidly studying this form of fat-oxidation catalysis without danger of interference from bacterial activity. This result with pure butterfat and an inorganic serum also showed that the oxidant effect is a direct one between the water phase and the fat; no other butter constituent such as phosphatide (cf. Barnicoat and Palmer, 1938) or ascorbic acid (cf. Krukovsky and Guthrie, 1945) is necessary as an intermediary. (The phosphatide content of the fat was 0·008 per cent.)

The synthetic inorganic butter-serum normally used contained 4·0 g. calcium chloride hexahydrate, 2·0 g. sodium citrate, and 2·0 g. potassium dihydrogen phosphate per litre. Salts and solutions were freed from traces of heavy metals by repeated extraction with a solution of dithizone in chloroform, followed by thorough washing with chloroform, the last traces of which were removed by boiling. Lea (1936) has questioned the value of some of his own experiments with sodium chloride solutions because of the possible presence of traces of heavy metals or other impurities, perhaps derived partly from the glass of the experimental vessel. In the present experiments the aqueous

solutions were dispersed in the fat so that only a very small fraction of the water phase would be in contact with the glass.

TABLE 1.—THE EFFECT OF ACID AND SALT IN ACCELERATING THE OXIDATION OF FAT IN PASTEURIZED HARDENED RECONSTITUTED BUTTER, AND IN BUTTERFAT CONTAINING DISPERSED SYNTHETIC INORGANIC SERUM.

| Sample. | | Oxidation Values of the Fat after Eight Days at 40°C. | | | |
|---|---|---|---|---|---|
| | | Lea Peroxide Value. | | Fat Aldehyde Value. | |
| * Pasteurized butter, pH 7·0, unsalted | A | 0·33 | 0·32 | 0·47 | 0·48 |
| | B | 0·30 | | 0·49 | |
| * Pasteurized butter, pH 7·0, + 2 per cent. salt. | A | 0·36 | 0·35 | 0·61 | 0·59 |
| | B | 0·34 | | 0·57 | |
| * Pasteurized butter, pH 5·0, unsalted | A | 0·34 | 0·35 | 0·60 | 0·57 |
| | B | 0·35 | | 0·54 | |
| * Pasteurized butter, pH 5·0, + 2 per cent. salt. | A | 0·47 | 0·47 | 1·28 | 1·28 |
| | B | 0·47 | | 1·28 | |
| * Butterfat + synthetic serum, pH 7·0 | A | 0·47 | 0·48 | 0·54 | 0·55 |
| | B | 0·48 | | 0·56 | |
| * Butterfat + synthetic serum, pH 5·0 | A | 0·62 | 0·60 | 0·57 | 0·57 |
| | B | 0·57 | | 0·57 | |
| * Butterfat + synthetic serum, pH 5·0, + 2 per cent. salt. | A | 1·42 | 1·35 | 3·9 | 3·9 |
| | B | 1·28 | | 3·8 | |

* In all tables of results the addition of 10 per cent. hydrogenated peanut oil is understood.

The pH of solutions was adjusted with caustic soda or sulphuric acid, using a Coleman glass-electrode pH meter. When salts were to be added it was found advisable to adjust the pH after adding the salt to the serum. The pH of dispersed solutions was checked after separation from the fat following incubation. In some cases, particularly with alkaline serum, there was a considerable change in pH during incubation. This drop in the pH of initially alkaline sera has also been observed in cold-stored butters (Loftus Hills, Scharp, and Bellair, 1934), and it could be due to interaction of hydroxyl ions with free fatty-acid in the fat. In figures and tables of results in this report, unless otherwise indicated, when the pH changed during storage the average of initial and final values has been given.

To maintain the aqueous phase in fine dispersion in the fat at 40°C. it was necessary to add 10 per cent. of fully hydrogenated peanut oil instead of the 4 per cent. used with a dispersed solid. In view of the low degree of unsaturation of this hydrogenated fat (iodine number less than 1·0), any effect on the chemical reactions being studied was regarded as negligible. The catalytic action of salt and acid on fat oxidation was found to be very sensitive to the fineness of dispersion of the solution in the fat. While with a dispersed solid phase it is possible to obtain very good agreement between duplicate treatments in oxidation tests, with a dispersed aqueous phase variations were more apparent in spite of every effort to standardize stirring procedure. The samples were hand-stirred during cooling, and the effect of the personal factor in

controlling fineness of distribution is apparent in many of the tables of results given below. The duplicate treatments A and B were stirred by different operators, and while both series reflect the relative effect of the various treatments, there is in some experiments considerable difference between the corresponding values of A and B.

Wiley (1939) found the Schibsted (1932) fat aldehyde determination particularly useful in following fat-oxidation in cold-stored salted acid butters, and this test was therefore used in the present work. Because the longer incubation period needed for application of the aldehyde test carried the range of fat-oxidation beyond the level at which the more sensitive thiocyanate peroxide test is particularly useful, the somewhat simpler Lea (1938) fat-peroxide test was used. The initial peroxide value of the butterfats was less than 0·05.

### 3. The Effect of Dispersed Water on Fat-Oxidation.

(i) *General.*

Studies of the effect of water on the oxidation of fat have been confused, as Lea (1938) pointed out, by the use of systems containing constituents other than water and fat. The work of Chapman and McFarlane (1946) shows how variation in the moisture content of milk powder will affect the rate of development from the protein of reducing substances having an antioxidant effect on the fat. In most mixed systems the effect of water on fat-oxidation is probably of a similar indirect nature.

There have been few investigations of the direct effect of water on fat-oxidation. Greenbank and Holm (1924) found that 4 per cent. of water agitated in butterfat at 95°C. extended the induction-period by 50 per cent. At lower temperatures they held fat in atmospheres of various humidities, which could affect only the amount of water dissolved in the fat, and obtained no very definite results. Briggs (1932) found that moisture (no concentration is given) had no effect on the rate of oxidation of butterfat at 100°C. Hughes and Rideal (1933) found that mono-molecular layers of eleostearic acid on dilute acid solution were completely oxidized in 15 minutes at 20°C. French, Olcott, and Mattill (1935) added small amounts of water to dried lard but found no change in the induction-period at 50°C.

(ii) *Experimental.*

From numerous experiments designed chiefly for study of the oxidant effect of acid and salt, data on the effect of distilled water and of synthetic inorganic butter-serum on the rate of oxidation of butterfat have been obtained. Typical results are given in Table 2. The distilled water was prepared from an all-pyrex still with a 15-in. splash-head, in constant use for over a year before these experiments were undertaken. In all cases the dispersed water or serum has accelerated oxidation.

(iii) *Discussion.*

An understanding of one possible mechanism of the catalytic activity of dispersed water may be obtained by considering in detail the conditions at the fat-water interface. With a moisture dispersion equivalent to that in butter the area of this interface is at least 500 sq. cm. per gram.

TABLE 2.—THE EFFECT OF WATER AND OF SYNTHETIC INORGANIC BUTTER-SERUM DISPERSED IN BUTTERFAT ON THE RATE OF OXIDATION.

| Sample. | | Oxidation Values of the Fat after Incubation at 40°C. | |
|---|---|---|---|
| | | Lea Peroxide Value. | Fat Aldehyde Value. |
| Butterfat 1 | A | 1·48 | 2·5 |
| | B | 1·46 | 2·4 |
| | Mean | 1·47 | 2·5 |
| Butterfat 1 + 16 per cent. distilled water | A | 1·74 | 3·5 |
| | B | 1·72 | 4·2 |
| | Mean | 1·73 | 3·9 |
| Butterfat 2 | A | 1·90 | 4·2 |
| | B | 1·84 | 3·8 |
| | Mean | 1·87 | 4·0 |
| Butterfat 2 + 16 per cent. distilled water | A | 2·14 | 5·5 |
| | B | 2·11 | 6·1 |
| | Mean | 2·13 | 5·8 |
| Butterfat 3 | A | 0·36 | 0·55 |
| | B | 0·34 | 0·57 |
| | Mean | 0·35 | 0·56 |
| Butterfat 3 + 16 per cent. distilled water | A | 0·50 | 0·89 |
| | B | 0·51 | 0·99 |
| | Mean | 0·51 | 0·94 |
| Butterfat 4 | A | 0·28 | 0·78 |
| | B | 0·27 | 0·73 |
| | Mean | 0·28 | 0·76 |
| Butterfat 4 + 16 per cent. distilled water | A | 0·54 | 1·54 |
| | B | 0·50 | 1·36 |
| | Mean | 0·52 | 1·45 |
| Butterfat 5 | A | 0·33 | .. |
| | B | 0·33 | .. |
| | Mean | 0·33 | .. |
| Butterfat 5 + 16 per cent. distilled water | A | 0·58 | .. |
| | B | 0·62 | .. |
| | Mean | 0·60 | .. |
| Butterfat 6 | A | 0·51 | 0·97 |
| | B | 0·50 | 0·93 |
| | Mean | 0·51 | 0·95 |
| Butterfat 6 + 16 per cent. distilled water | A | 0·69 | 1·50 |
| | B | 0·71 | 1·52 |
| | Mean | 0·70 | 1·51 |
| Butterfat 7 | A | 0·70 | 1·83 |
| | B | 0·70 | 1·89 |
| | Mean | 0·70 | 1·86 |
| Butterfat 7 + 16 per cent. distilled water | A | 0·96 | 2·62 |
| | B | 0·86 | 2·51 |
| | Mean | 0·91 | 2·57 |
| Butterfat 7 + 16 per cent. synthetic serum | A | 0·88 | 2·48 |
| | B | 0·81 | 2·44 |
| | Mean | 0·85 | 2·46 |

The work of Langmuir (1917), Harkins, Brown, and Davies (1917), and the later studies of Hughes and Rideal (1933) and Gee and Rideal (1935) have shown clearly the hydrophilic tendency of the double-bond in hydrocarbon chains. The latter workers, from surface potential measurements, found that the relative values of the vertical components of the effective electrical moments per molecule of the triglycerides were 10·0 for the glyceride group and 0·3 for the double bond. However, even highly compressed films of oleic acid were accelerated in oxidation by 0·0015 per cent. potassium permanganate solutions, indicating considerable access of the solution to the double bonds. The greater solubility in water of ethylene compared to ethane may also be taken as evidence of the hydrophilic nature of the ethylenic double-bond. At the interface between fat and dispersed water it is therefore to be expected that although for the most part the glyceryl group will be directed towards the surface, there will also be an appreciable concentration of double-bonds.

Farmer and Sutton (1943) and Atherton and Hilditch (1944) have shown that at 20°C. and 35°C. the initial interaction of oxygen with an unsaturated fat results in the formation of a hydroperoxide on a carbon atom adjacent to the double-bond carbon atoms. Farmer and Sundralingham (1942) point out that although the initial dissociation of hydrogen at this α-carbon atom is probably of a free-radical character and therefore favoured by a non-polar environment, the dissociation is also favoured by the normal electronic displacements in the double-bonded system. Exposure of the unsaturated carbon atoms to the polar solvent water, so strengthening the electronic displacements, while the α-carbon atoms remain in the non-polar fat phase, should therefore favour oxidation by assisting free-radical formation at the α-carbon atoms. In addition, interaction of peroxide radicals with water may produce OH radicals, and these may initiate further peroxide-forming reaction chains in the fat phase (cf. Baxendale, Evans, and Park, 1946), so providing an alternative path for propagation of the reaction. A third factor to be considered when dispersed water is present in an oxidizing fat is that the effectiveness and stability of antioxidants may be diminished, as Lovern (1946) has pointed out, and this may apply to the antioxidants occurring naturally in butterfat.

Hughes and Rideal (1933) have shown that in the oxidation of a mono-molecular layer of an unsaturated acid the first group formed (presumably the hydroperoxide) is strongly hydrophilic, having a vertical polarization potential greater than that due to one OH group. When a molecule of fat in a fat phase containing dispersed water has been oxidized, there will follow a tendency for the hydroperoxide group to move to the interface and to be oriented towards the water phase.

## 4. The Effect of Acid Sodium Chloride Solutions on the Oxidation of Butterfat.

### (i) *Traces of Heavy Metals.*

The commercial dairy salts commonly used in Australia contain about 1 p.p.m. of copper and 10 p.p.m. of iron. The use of such salt in butter would increase the heavy metal content by the equivalent of about 0·02 p.p.m. of copper. Barnicoat and Palmer (1938) attributed the adverse effect of salt on keeping quality in some of their experimental butters to traces of metallic oxidation catalysts. Pont (1945), Itzerott (1942), and Loftus Hills (1936) have found that differences of a few parts per hundred million in the copper content of stored butter are reflected in its keeping quality. The pH of the butters studied by these workers would have been mainly in the range 6·5 to 7·5. Davies (1933) has shown that in milk serum the fraction of the copper present which is ionized is increased a hundredfold when the pH is reduced from 6·6 to 5·4. Experiments were therefore carried out to determine whether the oxidant activity of salt in acid solution was due to traces of heavy metals. The rate of oxidation of butterfat containing a dispersed solution of commercial dairy salt was compared with that of butterfat containing a solution of A.R. grade sodium chloride previously purified by alkali precipitation, filtration, and neutralization, followed by the usual dithizone extraction. The results, shown in

Table 3, reveal that the difference in activity attributable to the heavy metal content of the commercial salt is slight, and that the sodium chloride is predominantly responsible for the acceleration of oxidation.

TABLE 3.—THE RELATIVE OXIDANT EFFECT OF COMMERCIAL DAIRY SALT AND OF PURIFIED SODIUM CHLORIDE ON BUTTERFAT.

| Experiment. | Sample. | Fat-Oxidation Values after Ten Days at 40°C. | | Final pH |
|---|---|---|---|---|
| | | Lea Peroxide Value. | Fat Aldehyde Value. | |
| A .. | Butterfat + 16 per cent. acid serum A | 0·85 | 1·17 | 5·00 |
| | Butterfat + 16 per cent. acid serum B | 0·87 → 0·86 | 1·06 → 1·11 | |
| | Butterfat + 16 per cent. acid serum + 2 per cent. purified NaCl A | 1·38 | 2·73 | 4·76 |
| | Butterfat + 16 per cent. acid serum + 2 per cent. purified NaCl B | 1·64 → 1·51 | 3·70 → 3·21 | |
| | Butterfat + 16 per cent. acid serum + 2 per cent. dairy salt A | 1·50 | 3·33 | 5·00 |
| | Butterfat + 16 per cent. acid serum + 2 per cent. dairy salt B | 1·63 → 1·55 | 3·78 → 3·55 | |
| | (After 9 days at 40°C.) | | | |
| B .. | Butterfat + 16 per cent. acid serum A | 0·67 | 0·94 | 5·18 |
| | Butterfat + 16 per cent. acid serum B | 0·64 → 0·65 | 0·66 → 0·80 | |
| | Butterfat + 16 per cent. acid serum + 2 per cent. purified NaCl A | 1·42 | 3·83 | 4·88 |
| | Butterfat + 16 per cent. acid serum + 2 per cent. purified NaCl B | 1·19 → 1·31 | 3·17 → 3·50 | |
| | Butterfat + 16 per cent. acid serum + 2 per cent. dairy salt A | 1·34 | 4·27 | 4·88 |
| | Butterfat + 16 per cent. acid serum + 2 per cent. dairy salt B | 1·49 → 1·42 | 4·44 → 4·36 | |

(ii) *General Salt Effect.*

The possibility that the catalytic activity of acid sodium chloride solutions was of a chiefly physical nature, perhaps a salt effect in acid catalysis, was then investigated. Comparative tests were made of the oxidant effect of several sodium and potassium salts dispersed in sera of low and high pH (5·0 and 6·6). The results, given in Table 4, show that while sodium chloride, sodium bromide, and potassium chloride accelerated the oxidation of the butterfat, sodium sulphate, neutral sodium phosphate, and potassium sulphate had if anything a slight retarding effect, so that no general salt effect is involved in this acceleration.

(iii) *The Catalysis of Fat-Oxidation by Cl− and H+ ions.*

The foregoing results made it clear that the sodium ions took no part in the action, and that of the anions tested only the halides were capable of showing combined action with hydrogen ions in accelerating oxidation of fat. Quantitative studies of the effect of variation in the concentration of chloride ions and of hydrogen ions were then undertaken, and the results are shown graphically in Figs. 1, 2, and 3. Increase of chloride ion concentration at pH 5·0 gave a steady increase in rate of oxidation. With constant sodium chloride content, fat-oxidation was accelerated slightly as the pH fell from 9·5 to 6·0, and below pH 6·0 the acceleration was very marked. Without added

sodium chloride, change in hydrogen ion concentration had little effect until the pH fell below 3·5; a small concentration of chloride ions would of course be present in the serum.

Table 4.—The Effect of Various Salts in Solution at two pH Levels on the Oxidation of Butterfat.

| Experiment. | Sample. | Fat-Oxidation Values after Ten Days at 40°C. | | Final pH. |
|---|---|---|---|---|
| | | Lea Peroxide Value. | Fat Aldehyde Value. | |
| L .. | Butterfat + 16 per cent. serum pH 6·6 | A 0·22, B 0·24 → 0·23 | A 0·13, B 0·12 → 0·13 | 6·60 |
| | Butterfat + 16 per cent. serum pH 5·0 | A 0·36, B 0·30 → 0·33 | A 0·18, B 0·14 → 0·16 | 4·96 |
| | Butterfat + 16 per cent. serum pH 6·6 + 2 per cent. NaCl | A 0·40, B 0·40 → 0·40 | A 0·18, B 0·23 → 0·21 | 6·15 |
| | Butterfat + 16 per cent. serum pH 5·0 + 2 per cent. NaCl | A 0·80, B 0·71 → 0·76 | A 1·26, B .. → 1·26 | 4·85 |
| | Butterfat + 16 per cent. serum pH 6·6 + 2 per cent. neutral sod. phosphate | A 0·23, B 0·23 → 0·23 | A 0·17, B 0·09 → 0·13 | 6·90 |
| | Butterfat + 16 per cent. serum pH 5·0 + 2 per cent neutral sod. phosphate | A 0·20, B 0·22 → 0·21 | A 0·10, B 0·09 → 0·10 | 6·80 |
| | Butterfat + 16 per cent. serum pH 6·6 + 2 per cent. KCl | A 0·33, B 0·36 → 0·35 | A 0·17, B 0·23 → 0·20 | 6·35 |
| | Butterfat + 16 per cent. serum pH 5·0 + 2 per cent. KCl | A 0·61, B 0·62 → 0·62 | A 0·81, B 0·81 → 0·81 | 5·05 |
| | Butterfat + 16 per cent. serum pH 6·6 + 2 per cent. $K_2SO_4$ | A 0·19, B 0·23 → 0·21 | A 0·14, B 0·11 → 0·13 | 6·90 |
| | Butterfat + 16 per cent. serum pH 5·0 + 2 per cent. $K_2SO_4$ | A 0·17, B 0·18 → 0·18 | A 0·13, B 0·13 → 0·13 | 5·45 |
| M .. | Butterfat + 16 per cent. serum pH 5·0 | A 0·85, B 0·87 → 0·86 | A 1·17, B 1·06 → 1·11 | 5·00 |
| | Butterfat + 16 per cent. serum pH 5·0 + 2 per cent. NaCl | A 1·38, B 1·64 → 1·51 | A 2·73, B 3·70 → 3·21 | 4·76 |
| | Butterfat + 16 per cent. serum pH 5·0 + 2 per cent $Na_2SO_4$ | A 0·67, B 0·68 → 0·68 | A 1·02, B 1·06 → 1·04 | 5·25 |
| N .. | Butterfat + 16 per cent. serum pH 7·0 | A 0·77, B 0·72 → 0·75 | A 0·86, B 0·86 → 0·86 | 6·80 |
| | Butterfat + 16 per cent. serum pH 5·0 + NaCl to make 3M soln. | A 1·66, B 1·58 → 1·62 | A 4·60, B 4·45 → 4·53 | 4·94 |
| | Butterfat + 16 per cent. serum pH 5·0 + NaBr to make 3M soln. | A 2·02, B 2·00 → 2·01 | A 5·35, B 5·80 → 5·58 | 4·94 |

The observation that this form of accelcration of fat-oxidation was due specifically to the combined effect of halide and hydrogen ions suggested that a purely chemical mechanism was involved. From the facts that chlorine is known to accelerate some other oxidations of the chain-reaction type, that hydrogen peroxide will produce chlorine in acid sodium chloride solutions, that the hydroperoxide group tends to move to the interface, and the perhaps somewhat lower peroxide to aldehyde ratio in fats oxidized by acid sodium chloride solution, it

appeared that some of the initially formed fat-hydroperoxide might be reacting with hydrogen and chloride ions to give chlorine. This would then induce further oxidation of the fat. The reaction might take the form:

$$R{-}O{-}O{-}H + 2Cl^- + 2H^+ \longrightarrow Cl_2 + H_2O + R{-}OH$$

If this were so it would be possible to show that fat-peroxide is capable of reacting with hydrogen and chloride ions to give free chlorine; and that free chlorine accelerates the oxidation of butterfat.

It had previously been observed that commercial dairy salt treated with chlorine for 24 hours, and then repeatedly vacuum-treated, when dispersed in dry butterfat oxidized the fat more rapidly than untreated salt. The oxidation values of the fats are shown in Table 5.

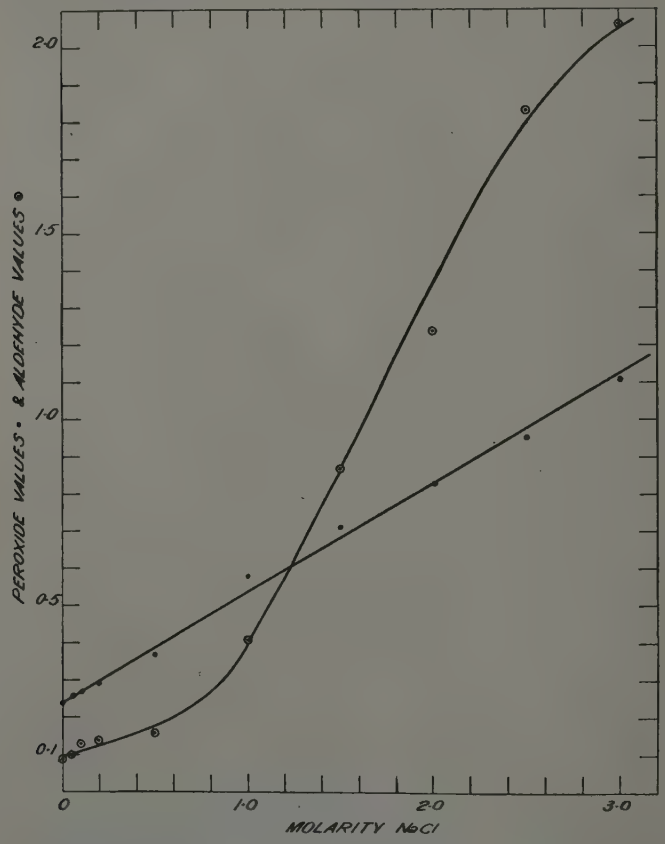


Fig. 1.—The relationship between sodium chloride concentration in a dispersed synthetic butter-serum at pH 5·0 and the oxidation values of the fat after incubation at 40°C.

TABLE 5.—THE EFFECT OF EXPOSURE OF DAIRY SALT TO CHLORINE ON ITS OXIDANT ACTIVITY WHEN DISPERSED IN THE DRY STATE IN BUTTERFAT.

| Sample. | Fat-Oxidation Values after Thirteen Days at 40°C. | |
|---|---|---|
| | Lea Peroxide Value. | Fat Aldehyde Value. |
| Fat + 5 per cent. dairy salt dispersed in a finely ground state { A | 2·40 | 7·07 |
| { B | 2·70 } 2·55 | 9·47 } 8·27 |
| Fat + 5 per cent. chlorine-treated dairy salt dispersed in a finely ground state { A | 3·15 | 9·26 |
| { B | 3·35 } 3·25 | 10·70 } 9·98 |

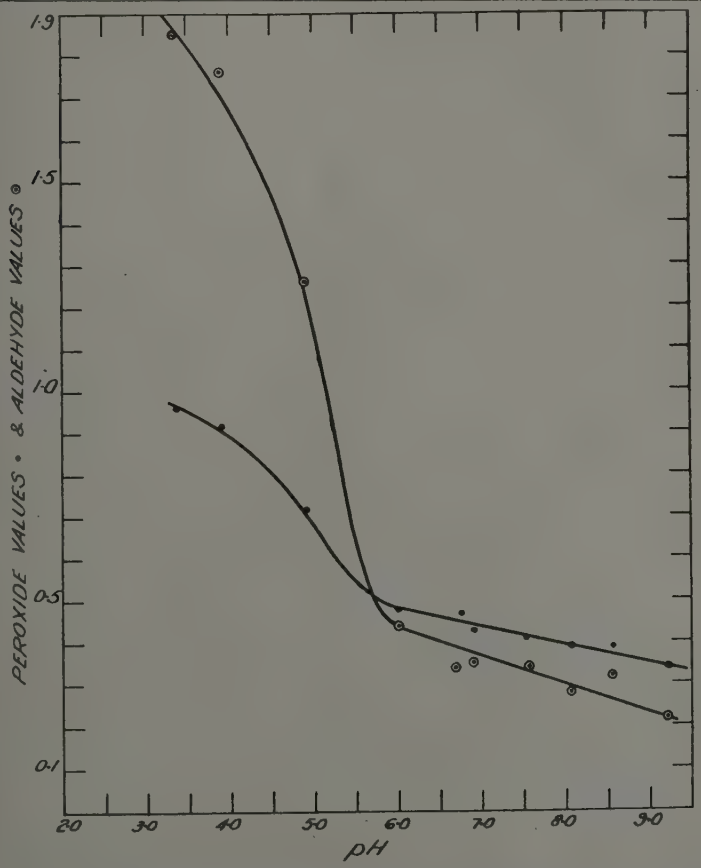


FIG. 2.—The relationship between the pH of a dispersed synthetic butter-serum containing 1·7M NaCl and the oxidation values of the fat after incubation at 40°C.

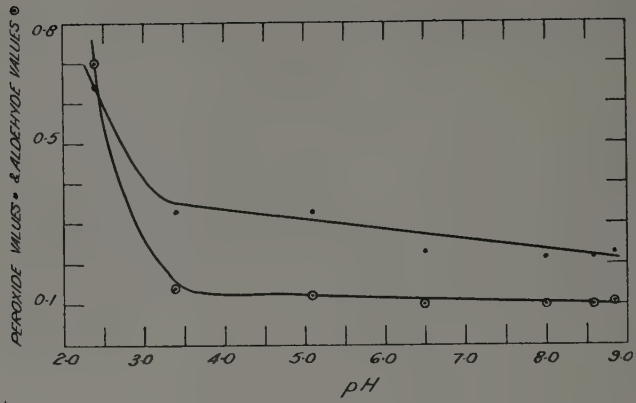


Fig. 3.—The relationship between the pH of a dispersed synthetic butter-serum (without added sodium chloride) and the oxidation values of the fat after incubation at 40°C.

When synthetic butter-serum at pH 4·8, without added chlorine, with 12·5 p.p.m. of chlorine, and with 37·5 p.p.m. of chlorine, was dispersed in butterfat, the oxidation values shown in Table 6 were obtained after incubation. There was a slight but irregular increase in rate of oxidation when chlorine was present. It was found that when such quantities of chlorine were added to the synthetic butter-serum they disappeared within a few minutes. This was traced to reaction with the citric acid. When the dispersed water was buffered only with potassium dihydrogen phosphate, the accelerating effect of 10 p.p.m. of

Table 6.—The Effect of Chlorine in Dispersed Serum Containing Citrate on the Oxidation of Butterfat.

| Sample. | | Fat-Oxidation Values after Fourteen Days at 40°C. | | | |
|---|---|---|---|---|---|
| | | Lea Peroxide Value. | | Fat Aldehyde Value. | |
| Fat + 16 per cent. serum, pH 4·8 .. .. | | 0·44<br>0·44 | 0·44 | 0·90<br>0·84 | 0·87 |
| Fat + 16 per cent. serum containing 12·5 p.p.m. chlorine, pH 4·8 | A | 0·52 | 0·51 | 1·15 | 1·03 |
| | B | 0·49 | | 0·92 | |
| Fat + 16 per cent. serum containing 37·5 p.p.m. chlorine, pH 4·8 | A | 0·57 | 0·54 | 0·90 | 0·77 |
| | B | 0·51 | | 0·64 | |

chlorine on fat-oxidation was more marked, but in further experiments amounts of chlorine even up to 200 p.p.m. showed little effect on rate of oxidation.

Chlorine solution was dispersed in fat in the normal way by stirring in an ice-water bath until the fat hardened, and was then immediately re-separated from the fat by melting and centrifuging. No chlorine remained in solution, nor could any chlorine be detected in solution in the fat. (Absence of alteration in the iodimetric peroxide value of

the fat was taken as evidence that no free chlorine was present). The chlorine had apparently undergone rapid reaction with the fat. To reproduce more closely the conditions existing in fat oxidizing under the influence of acid sodium chloride solution, where chlorine would be continuously formed, and where chloride ions would also be present, 25 g. of butterfat were held at 40°C. over a layer of 25 ml. of water containing 1800 p.p.m. of chlorine and adjusted to pH 5·0. (To allow for the sodium chloride formed during this pH adjustment, an equivalent amount of sodium chloride (0·2 per cent.) was added to the control.) The results of this experiment, recorded in Table 7, show that under these conditions chlorine has a rapid oxidizing action on butterfat.

TABLE 7.—THE EFFECT OF CHLORINE SOLUTION (1800 p.p.m.) ADJUSTED TO pH 5·0, ON THE OXIDATION OF AN OVERLYING LAYER OF BUTTERFAT.

| Sample. | | Fat-Oxidation Values after Six Days at 40°C. | | | |
|---|---|---|---|---|---|
| | | Lea Peroxide Value. | | Fat Aldehyde Value. | |
| Fat over buffer solution pH 5·0 | A | 0·26 | 0·25 | 0·18 | 0·17 |
| | B | 0·25 | | 0·18 | |
| | C | 0·27 | | 0·17 | |
| | D | 0·23 | | 0·13 | |
| Fat over buffer solution containing 1800 p.p.m. chlorine, pH 5·0 | A | 2·32 | 2·25 | 6·7 | 7·2 |
| | B | 2·29 | | 7·1 | |
| | C | 1·99 | | 6·7 | |
| | D | 2·40 | | 8·3 | |

The absorption of chlorine by butterfat revealed in these tests made difficult the demonstration of the production of free chlorine by the action of oxidized fat on acid sodium chloride solutions. To reduce the rate of absorption of chlorine the fat was dispersed in a solvent. It was necessary to have a solvent which would not itself absorb chlorine, and carbon tetrachloride was therefore chosen. This necessitated control experiments to show that chlorine was not derived from carbon tetrachloride under the experimental conditions.

A saturated sodium chloride solution at pH 3·3 was warmed and agitated with a 5–10 per cent. solution of fat in carbon tetrachloride. A small amount of o-tolidene was added for the detection of free chlorine. With oxidized peanut oil and oxidized butterfat a slight but definite yellow colour developed. With unoxidized oils and fats, or with oxidized fats in carbon tetrachloride but with water instead of sodium chloride solution, the solutions remained colourless. The use of either benzoyl peroxide or hydrogen peroxide in place of the oxidized fat gave a yellow colour with o-tolidene. When, instead of acid sodium chloride solution, a concentrated solution of magnesium chloride, not acidified, was used in these experiments, chlorine formation was somewhat stronger.

The formation of chlorine under these conditions was confirmed by passing nitrogen through a mixture of carbon tetrachloride solution of fat and saturated sodium chloride solution at pH 3·3 at 60°C. The

nitrogen was led through a reflux condenser and filter-plug to an indicator tube containing acid potassium iodide and starch. A distinct purple colour developed. When the experiment was repeated with unoxidized fat or with no fat present, the indicator solution remained colourless.

(iv) *Discussion.*

There is little information in the literature on the activity of halide ions in catalysing oxidations. Mapson (1941, 1945) found that while sodium chloride accelerated the oxidation of ascorbic acid by hydrogen peroxide when copper was present, apparently through its effect on the cupric-cuprous system, the oxidation of ascorbic acid by atmospheric oxygen was accelerated by small concentrations of chloride ion but inhibited by larger concentrations. The oxidation of ascorbic acid is a dehydrogenation and does not involve a peroxide stage.

Hofmann, Quoos, and Schneider (1914) studied the oxidation of organic compounds such as aniline and hydroquinone, and also of potassium iodide, by chlorates. These actions were accelerated by the chlorides of magnesium, calcium and lithium, and in experiments in which acid was present, by sodium chloride. The authors attributed the catalytic activity to the "undissociated salts," and considered that magnesium chloride was several times as effective as sodium chloride. Since this may have been due to difference in pH, some of their experiments were repeated and it was found that, when the pH of the solutions was controlled, magnesium chloride was only slightly more effective than sodium chloride in equivalent concentration. It seemed likely that this catalysis also might involve the formation of chlorine, and it was readily shown with o-tolidene that when potassium chlorate was mixed with solutions of chlorides at the concentrations used, chlorine was formed.*

The oxidant action of chlorine solutions on butterfat no doubt arises from the liberation of activated oxygen from the water through the formation of hypochlorous acid. The oxidant action of acid sodium chloride solutions may, following the formation of free chlorine, take a similar course. However, the rapid absorption by fat of free chlorine from a dispersed water phase without necessarily accelerated oxidation suggests that a somewhat different mechanism is involved. Schumacher (1936), Chapman (1934), and others have studied the catalytic activity of the halogens in the photo-chemical oxidation of olefinic compounds, and have concluded that the halogen atoms liberated by the light energy are responsible for the radical formation which precedes oxidation. Kharasch and others (cf. Kharasch, Mansfield, and Mayo, 1937) have concluded that halide atoms may be formed by the action of peroxides on the halogen acids. It is therefore possible that in the oxidation of butterfat by acid sodium chloride solution, atomic as well as molecular chlorine is formed. The relative ease with which atomic bromine could be formed would account for the greater activity of sodium bromide in equivalent concentration (see Table 4). It is probable that molecular chlorine, atomic chlorine, and perhaps oxides of chlorine, are all formed to varying degrees at the interface.

The ability of acid sodium chloride solutions to accelerate fat-peroxide formation as well as the later stages of fat-oxidation, in spite

* Since this work was completed Dr. D. Bunn (*Trans. Faraday Soc.*, 42: 192, 1946) has reported the catalytic effect of chloride ion in persulphate oxidations and has recorded the liberation of chlorine from aqueous mixtures of persulphate and chloride at 25°C.

of the assumed destruction of peroxide, may best be understood by reference to the chain reactions involved. The normal peroxide formation chain reaction proceeds through the formation of peroxide free-radicals in the following way:

$$R{-}O{-}O{-} + R{-}H \longrightarrow R{-}O{-}O{-}H + R{-}$$
$$R{-} + O_2 \longrightarrow R{-}O{-}O{-}$$

By reaction of some of the R-O-O-H molecules with hydrogen and chloride ions to give chlorine, new chain reactions can be initiated without affecting the original chain. If the R-O-O- radicals react with the ions in the water phase to give chlorine, which then initiates further reaction chains, an alternative path for propagation of the reaction becomes available. This would provide an example of catalysis by intermediate reactions, a common form of catalysis in chain reactions.

The oxidant activity of traces of magnesium chloride on salt dispersed in dry butterfat is due no doubt to a similar mechanism to that which has been suggested for acid sodium chloride solutions. The pH of concentrated solutions of magnesium chloride is below 5·0, so that both chloride ions (in much higher concentration than in saturated sodium chloride) and hydrogen ions will be present. The ready formation of chlorine from concentrated magnesium chloride solutions by oxidized fat was shown experimentally. Because of the much greater solubility in water of magnesium chloride, it is present in commercial salt as a film on the surface of the sodium chloride crystals. The deliquescent nature of the magnesium chloride ensures that this film will be in the form of a concentrated solution. The oxidant activity of the traces of magnesium chloride in commercial salt when dispersed in butterfat can thus be attributed to the particularly favourable physical condition in which the magnesium chloride is present. When the commercial salt is dissolved the magnesium chloride is no longer concentrated at the interface but is dispersed through the solution in a very dilute form and can no longer appreciably affect fat-oxidation.

The other chlorides which were found to have an oxidant effect in dry butterfat (aluminium, beryllium, calcium, and zinc) are all both deliquescent and acidic. The observation of Hofmann, Quoos, and Schneider that lithium chloride solution, without addition of acid, was nearly as effective as magnesium chloride in catalysing the oxidation of aniline hydrochloride by chlorate may be due in part to the hydrolysis which this salt undergoes in solution, and in part to its facility in forming complexes with organic compounds. This latter characteristic is shared by magnesium chloride and may account for some part of its activity.

Although it has been shown that a direct catalytic action occurs between butterfat and a dispersed acid sodium chloride solution, in butter the protein-phosphatide complex, because of its physical distribution (i.e., at the interface), is likely to take an important part in the reaction. The fatty-acid portion of the phosphatide molecules will be mainly oriented into the fat phase, and the double-bonds and peroxide groups in these fatty acids will no doubt function in a similar way to the same groups in the triglycerides. Conditions in frozen butter will also differ in another way from the conditions of the experimental technique. At temperatures down to −22°C., within each droplet, ice will be crystallized from the serum, so increasing the concentration of salt and acid in the liquid serum. This, together with the maintenance of finer moisture distribution than is possible at 40°C., will accentuate the catalysis.

## 5. Practical Considerations.

The type of mechanism which has been suggested for the oxidative action of acid and salt in cold-stored butter may usefully be considered in relation to butter-making practice and theory. From it may be derived several lines of practical experiment, only a few of which have so far been briefly investigated.

The need for using sodium chloride as the preservative salt in butter was first studied. The chloride anion is not particularly effective in checking bacterial growth, and other sodium salts could therefore give equal preservative action. Tests were made with salts known to be edible. Sodium citrate and sodium lactate had very little flavour. Sodium acetate tasted of vinegar. Neutral sodium phosphate had a slight earthy flavour and was fairly salty. The calcium salts tasted were all bitter. It soon became clear that the particular salty flavour necessary is a characteristic of sodium chloride. The slight flavour of neutral sodium phosphate and its buffering capacity (see Table 4) could perhaps be used, by incorporating a proportion of it in the salt added to the butter, to bring the pH of ripened cream butters up to a level at which fat-oxidation would be materially reduced.

Since the interaction between fat and salt solution takes place at the interface, the addition of surface-active substance not susceptible to oxidation might in effect blanket the surface and stop the reaction. In butterfat, glyceryl monostearate added at the rates of 0·1 and 1·0 per cent. was found to be quite ineffective for this purpose. This may be due to the fact, shown by Hughes and Rideal, that a single OH group is less hydrophilic than the hydroperoxide group. In butter, substances with a high degree of surface activity would be needed to displace the protein-phosphatide complex from the interface. Surface active substances with antioxidant properties should be particularly effective.

Early experiments in the United States indicated that overworking of butter leads to loss of keeping quality (Rogers, 1909). Hunziker (1940) attributes this to the increased surface area of air in such butter. However, in any butter sufficient air will be initially in solution in the butterfat (cf. Loftus Hills and Conochie, 1945*b*) to support a considerable degree of flavour change, and diffusion of oxygen through the fat occurs rapidly. A more reasonable explanation is to be found in the observed sensitivity of the salt-and-acid-catalysed oxidation of fat to the area of interface, and the fact that the butters made at that time were salted and of low pH. The present tendency of progressive buttermakers in Australia is to believe that, within the practical limit imposed by sticking of the butter to the churn, working should be as thorough as possible to minimize bacterial activity. Australian butters are approximately neutral. Although with neutral sodium chloride solutions dispersed in butterfat there is an oxidant action, in butter the antioxidant effect of the other serum constituents, shown by Barnicoat and Palmer, may be more important. The results given in Table 1 suggests that this is so, and therefore, given serum correctly adjusted in pH and free from heavy metal contamination, extensive working should not, through any effect on rate of fat-oxidation, adversely affect the keeping quality of salted neutral butters in cold-storage.

It is of interest to note that the peroxide groups, being attracted to the interface, will be subject not only to reactions favouring further oxidation, but also to non-propagative reactions. The antioxidant

effect of serum constituents must depend on such negative catalysis by breaking of the peroxide-forming reaction chains when peroxide groups are exposed at the interface In such reactions the serum constituents will themselves be oxidized. Oxidation initiated in the fat (in which oxygen is much more soluble than in water) could thus play an important part in oxidation of the non-fat constituents of butter.

The lower rate of oxidation of butterfat containing dispersed brine as the pH is increased to 9·5 does not necessarily mean that the optimum pH for the keeping quality of butter in cold-storage is higher than the accepted figure of about 7·0. The upper limit of pH for cold-storage butters is likely to be determined, not by oxidation of the fat, as is sometimes suggested, but by changes in the non-fat constituents of the butter, which certainly occur more readily at a slightly alkaline reaction.

## 6. Acknowledgments.

The authors gratefully acknowledge the assistance in laboratory work given by R. Wilkinson, and the facilities for the supply of churned butter granules given by Messrs. Holdensen and Nielson Pty. Ltd., through Mr. H. Joyce.

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# Note on the Effect of Phosphatide on the Ferric Thiocyanate Method of Estimating Peroxide in Fats.

*G. Loftus Hills, B.Agr.Sc.,* and R. Wilkinson.**

*Summary.*

Milk phosphatide at a concentration of 0·05 per cent. was found to interfere with the ferric thiocyanate test for peroxide groups in fats. This does not cause difficulty in the application of the test to dairy products other than dried buttermilk when benzene-methanol is used as the solvent. Acetone will not dissolve phosphatide to cause interference.

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The oxidation of ferrous ions to ferric ions in an organic solvent, and estimation of the ferric ions as thiocyanate, provides a sensitive index of the peroxide groups in oxidizing fats and oils (Lips, Chapman, and McFarlane, 1943; Loftus Hills and Thiel, 1946). The test is readily applicable to dried milk, the benzene-methanol solvent in which the test as performed being used to extract the fat from the milk powder.

In applying this test to a sample of dried buttermilk it was found that although some degree of oxidation was to be expected from the condition of the powder, no colour developed in the extract. Furthermore no colour appeared when 0·05 g. of a highly oxidized fat (P.V. = 30) was added to the solution.

A benzene-methanol extract of dried buttermilk should differ from an extract of dried whole milk in having approximately one-third the fat content, but about four times the phosphatide content. That the additional phosphatide was responsible for the interference with the peroxide test appeared possible from the known interference by phosphoric acid in the thiocyanate test for ferric ions in aqueous solution.

Milk phosphatide was prepared from fresh dried buttermilk by extraction with benzene-methanol, removal of the solvent in a continuous vacuum evaporator, and repeated solution of the fatty extract in benzene and precipitation with acetone. This phosphatide was added in graded amounts to a series of solutions of 0·1 g. of a slightly oxidized butterfat in 10 ml. benzene-methanol, and the peroxide determined by the usual procedure. The results of two such experiments are shown in Table 1.

It is clear that more than 5 mg. of phosphatide in 10 ml. of solution seriously interferes with this test. With butterfat obtained from milk, cream, or butter by the prescribed method the amount of phosphatide from a 0·5 g. sample of fat will be of the order of 0·05 mg. and therefore no interference will take place. With whole milk powder the amount of phosphatide available per 10 ml. of extract, using 0·75 g. of milk powder in 15 ml. solvent, will be about 1·2 mg., and it is unlikely that all of this will be extracted in five minutes. It may nevertheless be sounder practice to reduce the weight of milk powder taken from 0·75 g. to 0·5 g. in 15 ml. of solvent. With dried buttermilk the phosphatide present will be equivalent to 5–10 mg. per 10 ml. of solvent, and interference can be expected unless the weight of dried buttermilk taken is reduced.

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Table 1.—The Effect on the Peroxide Value of Varying Additions of Phosphatide to 10 ml. of Benzene-Methanol Containing 0·1 g. Fat.

| Weight of Phosphatide Added | Peroxide Value Recorded | |
|---|---|---|
| | Fat 1 | Fat 2 |
| None | 0·36 | 0·49 |
| 5γ | 0·36 | 0·42 |
| 10γ | 0·34 | 0·47 |
| 25γ | 0·35 | 0·49 |
| 50γ | 0·35 | 0·50 |
| 100γ | 0·36 | — |
| 250γ | 0·36 | 0·49 |
| 500γ | 0·35 | 0·51 |
| 1 mg. | 0·34 | 0·47 |
| 5 mg. | 0·27 | 0·42 |
| 10 mg. | 0·18 | 0·13 |
| 25 mg. | 0·00 | 0·03 |
| 50 mg. | 0·00 | 0·03 |

Acetone containing 0·05 per cent. butterfat was boiled with and without added phosphatide for five minutes and then decanted. The peroxide values of the two solutions by the thiocyanate method were found to be identical. Even in the presence of fat, phosphatide is not sufficiently soluble in boiling acetone to interfere with the peroxide determination. This was confirmed by extracting 0·75 g. dried buttermilk with 15 ml. acetone. When oxidized fat was added to this extract and tested for peroxide the correct increment in peroxide value was recorded. Acetone could therefore be used, in spite of its other disadvantages, in place of the benzene-methanol mixture for peroxide determinations in buttermilk powder.

An earlier observation in this laboratory that wheat-germ oil gave no peroxide reaction when tested by the ferric thiocyanate method is probably to be explained by interference by phosphatides. The oil was subsequently found to contain 6·8 per cent. of phosphatide.

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# The Washing of Butter and its Effect on Curd Content and Quality

*By E. G. Pont, M.Sc.Agr.**

*Summary.*

Seventy-four experimental churnings of butter manufactured without the use of any wash water were made during the 1945-46 export season at five Victorian factories selected to give a range of cream type and grade. In only two instances was there any difference in quality between the unwashed butters and their washed controls when graded one week after manufacture. In both cases the unwashed butter was graded one point higher.

After three months storage the washed butter was graded higher in 36 out of 68 cases. The unwashed butter was graded higher in 16 instances, and no distinction was made in 16 instances. The mean loss of grade was 1·23 points with the washed and 1·71 points with the unwashed butters. The mean difference in grade between the two classes of butter after storage was, statistically, highly significant. There did not appear to be any relationship between the inferior keeping quality of the unwashed butters and differences in curd content, initial quality, or the results of bacterial examinations.

The curd contents of the washed butters averaged 1·10 per cent. and of the unwashed butters 1·52 per cent. It is concluded that the mere presence of increased curd in this range is not a determining factor in keeping quality. When butter is made without washing, however, there appears to be a likelihood of introducing other factors, adverse in this respect, which were not covered by the present investigation.

## 1. Introduction.

The washing of butter at the grain stage during manufacture is a time-honoured practice and has as its chief object the removal of free buttermilk from the churn and the consequent reduction to a minimum of the curd content of the butter. Although this has long been believed to be essential in the interests of butter quality, little or no experimental evidence appears to have been adduced in support of the belief. In Danish experiments (1939) involving the use of an all-metal churn, the working of the butter in a highly plastic condition, and its removal from the churn with compressed air, best results from the viewpoint of quality were achieved in the complete absence of washing. Jensen *et al.* (1942) reported that by modifying the usual Victorian methods of butter manufacture the curd content was raised from 0·9 to 1·5 per cent. without impairing quality.

The elimination of washing has obvious economic advantages apart from the gain in over-run to be expected from an increased curd content. The widespread adoption of such a practice, however, must depend in the final result upon its effect on quality and more definite evidence in this respect seems desirable. This report gives the results of an investigation into the manufacture of unwashed butter in relation to the effect on curd content, the bacteriological condition, initial quality, and quality after storage for three months.

## 2. Procedure.

Five Victorian factories participated in the investigation which extended over three months during the export season. The individual factories were selected to give a range of cream type and quality. In

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each case the butter was manufactured under normal commercial conditions. On two days in each week a churn of butter was made entirely without washing, and buttermilk was used if water was required to make up moisture during working. The control was a churning washed in the normal way and made in the same churn from the same vat of cream. The factories were asked to chlorinate all wash water used. A box from each of the experimental churnings was graded together with its control, initially about seven days after manufacture and finally after three months storage at 16°F., by a panel of qualified graders. The graders were not told which was the experimental and which was the control butter. The butters were also analysed for curd, salt, and moisture, and bacteriological examinations were made before and after storage. The remainder of the butter was exported shortly after the initial grading and an endeavour was made to have it specially graded in London, but reports for only about one-fifth of the quantity exported were received. A total of 74 churns of unwashed butter was made, but at various stages a small proportion of the butters was lost from the experiment which aimed to interfere as little as possible with routine manufacturing, grading, and export procedures. In one case (Factory E) only four unwashed churnings were made because of shortages of cream supplies, and of these only two were available for complete grading and analysis.

### 3. Methods of Analysis.

Butters were analysed for moisture, salt, and curd according to the British Standard Methods (1938) with the following modifications. Samples (about 2 oz. in size) were prepared for analysis by preliminary warming at 30°C. in an airtight stoppered jar and working in the warm plastic condition with a steel spatula. They were allowed to regain room temperature before 5–6 g. was weighed out for analysis. After the moisture determination the fat was extracted with at least five successive 10-ml. lots of petroleum ether, the washings being drawn by gentle suction through a Gooch crucible containing purified washed asbestos. The contents of the moisture dish and Gooch crucible were dried at 100°C. for 1 hour and washed with hot distilled water into a beaker for the salt determination.

In order to minimize inequalities of distribution, three separate 1-oz. samples were taken from widely separated portions of the box for bacteriological examination. These were melted together at 42°C. and a 10-ml. sample transferred to a 90-ml. dilution flask of quarter-strength Ringer's solution. For total counts plates were made in triplicate in a dilution of 1/1,000, using the standard tryptone-glucose-milk agar of the American Public Health Association, and incubated for five days at 30°C. For yeast counts and coliform counts plates were made respectively on acidified malt agar (pH 3·5) and desoxycholate agar (Leifson, 1935) in a dilution of 1/10.

### 4. Results.

*(a) The Curd Contents of Washed and Unwashed Butters.*

The summarized results of curd analyses are shown in Table 1. It will be observed that the unwashed butters show a substantial increase in curd content, the mean of the washed butters being 1·10 per cent.

and of the unwashed 1·52 per cent. A tendency to variation in results from factory to factory is shown, particularly in the low figures from factory B with unwashed butter, and factory D with high values for washed butters. The reasons for these departures from the average are probably linked up with factory practice, particularly in relation to dilution and standardization of cream prior to pasteurizing, but no inquiries were made into this aspect.

TABLE 1.—RESULTS OF CURD ANALYSES OF WASHED AND UNWASHED BUTTERS.

| Factory. | Washed Butters. | | | Unwashed Butters. | | | |
|---|---|---|---|---|---|---|---|
| | Number of Samples. | Range. | Mean (*a*). | Number of Samples. | Range. | Mean (*b*). | Mean Increase (*b*–*a*). |
| | | % | % | | % | % | % |
| A .. | 13 | 1·07–1·25 | 1·15 | 13 | 1·45–1·75 | 1·58 | 0·43 |
| B .. | 14 | 0·79–1·22 | 1·07 | 14 | 1·01–1·59 | 1·38 | 0·31 |
| C .. | 27 | 0·69–1·28 | 1·03 | 27 | 1·27–1·79 | 1·55 | 0·52 |
| D .. | 14 | 0·97–1·48 | 1·25 | 14 | 1·32–1·79 | 1·54 | 0·29 |
| E .. | 3 | 0·87–1·08 | 0·98 | 3 | 1·49–1·57 | 1·53 | 0·55 |
| Overall Mean Values | 71 | 0·69–1·48 | 1·10 | 71 | 1·01–1·79 | 1·52 | 0·42 |

The average value for curd in the washed butter is higher than the figure of 0·9 per cent. generally accepted as being usual for Victorian butter. The latter figure is mostly based on results obtained by the Kohman (1919) rapid method of total analysis. In order to throw some light on this point a series of six butters including four washed and two unwashed were analysed in duplicate by both the method used in this investigation and by the standard Kohman method. The mean curd value obtained by the former technique was 1·19 per cent. and with the latter 1·10 per cent. The mean moisture values were 15·60 and 15·53 per cent. respectively. The results suggested that the comparatively high curd values obtained for the washed butters in the present investigation were due in part at least to the method of analysis employed. The lower curd values given by the Kohman method are presumably due to loss of curd during fat extraction and/or loss of bound moisture due to charring of the curd.

*(b) Grading Results Before and After Storage.*

In the initial grading a distinction was made on only two occasions between an unwashed butter and its control and in both instances the unwashed butter was judged higher by one point. After storage, however, as will be seen from Table 2, the washed butter was preferred in 36 instances, no distinction was made in sixteen instances and in sixteen cases the unwashed butter was graded higher. The average loss in grade was 1·23 points with the washed and 1·71 points with the unwashed butters.

A statistical analysis of the grade results, complete for 68 experiments, can be summarized as follows. The mean reduction in grade after storage of the unwashed butter compared with the washed was

0·48 points with a standard error of 0·15. The value of P was less than 0·01, indicating that the observed deleterious effect of not washing on keeping quality was highly significant. Although there appeared to be large variations in the effect between different factories these variations were not statistically significant. There was no significant correlation between the individual differences in grade after storage and the differences in curd content between the two classes of butter, the correlation co-efficient for these two sets of results being +0·1143.

Examination of Table 2 indicates that the inferior keeping quality of the unwashed butter was not associated with the initial quality of the butter. The common belief that thorough washing is especially desirable with butter made from second-grade cream is not supported by the results from factory D.

TABLE 2.—SUMMARY OF GRADING RESULTS.

| Factory. | Number of Expts. | Initial Grading (Washed Butters). | | Grading after Storage. Highest Grade Score to.— | | | Average Number Points Lost in Storage | |
|---|---|---|---|---|---|---|---|---|
| | | Range. | Average Grade. | Washed Butter. | Unwashed Butter. | No Distinction. | Washed Butter. | Unwashed Butter. |
| A .. | 12 | 91–93 | 92·1 | 5 | 4 | 3 | 1·08 | 1·21 |
| B .. | 14 | 92–93 | 92·9 | 12 | 1 | 1 | 1·07 | 1·89 |
| C .. | 26 | 92–93 | 92·4 | 10 | 7 | 9 | 1·29 | 1·62 |
| D .. | 14 | 84–90 | 87·5 | 7 | 4 | 3 | 1·43 | 1·93 |
| E .. | 2 | 93 | 93·0 | 2 | .. | .. | 1·0 | 3·0 |

*(c) Bacteriological Results.*

A summary of the bacteriological results in respect of total counts is given in Table 3. As is usual, considerable variation in counts of individual butters was encountered but the logarithmic averages of counts from different factories show trends which are of some interest. With factories B and C a substantial increase in bacterial numbers was evident when butter was left unwashed. In factories D and E on the other hand washing resulted in a significant increase in bacterial count. After storage there was a general tendency for counts to increase, presumably because of opportunities for bacterial growth in the times taken for the butter to drop to storage temperature and to reach room temperature again at the second examination. The differences in counts between the two series of butters were not so evident after storage. Yeast and coliform counts throughout showed wide and extreme variations and apart from some degree of correlation with the total counts showed no trends which would justify their presentation.

From these results it would appear that bacterial activity has had little or no effect on quality. Factory A for instance had much higher counts than factory B in both series of butters, but no difference was shown in the keeping quality of the washed butters from the two factories, and with the unwashed butters the advantage lay with factory A. With factories D and E the higher counts in the washed butters were not associated with any relative inferiority in keeping quality in comparison with the unwashed series.

## 5. Discussion.

In recent years the possibility of dispensing with the use of wash water in butter manufacture has attracted the interest of a number of Victorian factories. The results of the present investigation indicate that while this practice is without apparent effect on initial quality, it is accompanied by an element of risk to the keeping quality of the resultant butter. Although there were frequent instances of the unwashed being equal to or even better in keeping quality than the washed product, the overall results indicate a slight superiority of the latter type of butter in this respect.

The absence of correlation between differences in keeping quality and differences in curd content between the two classes of butter suggests that the presence of increased curd is not in itself a deleterious factor in quality determination. It would appear that there are factors associated with this aspect of butter manufacture which were not included in the scope of the investigation. One of these is the possible need for modification of manufacturing technique when washing is not practised. In the present investigation this point was left to the discretion of the individual factories. The degree to which heavy-metal contamination may have been affected by washing is an example of another factor which may have exerted a controlling effect on keeping quality.

Considerable simplification of factory procedure and reduction in costs is involved in the manufacture of unwashed butter. The question as to whether the slight inferiority shown by such butter in this experiment can be overcome by a more exact knowledge of the factors involved is of some importance and further investigation to this end is intended.

TABLE 3.—SUMMARY OF BACTERIOLOGICAL RESULTS

| Factory. | Initial Counts (Total). | | | | | Total Counts after Storage. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of Paired Samples. | Number of Times Highest Count given by— | | Mean Count per ml. (Logarithmic). | | Number of Paired Samples. | Number of Times Highest Count given by— | | Mean Count per ml. (Logarithmic). | |
| | | Washed. | Unwashed. | Washed. | Unwashed. | | Washed. | Unwashed. | Washed. | Unwashed. |
| A .. .. | 12 | 5 | 7 | 343,000 | 366,000 | 12 | 6 | 6 | 434,000 | 692,000 |
| B .. .. | 14 | 4 | 10 | 18,000 | 40,000 | 13 | 6 | 6 | 56,000 | 61,000 |
| C .. .. | 25 | 6 | 19 | 80,000 | 161,000 | 26 | 13 | 13 | 121,000 | 119,000 |
| D .. .. | 14 | 11 | 3 | 233.000 | 100,000 | 13 | 9 | 4 | 374,000 | 270,000 |
| E .. .. | 3 | 3 | 0 | 292,000 | 78,000 | 2 | 1 | 1 | 46,000 | 135,000 |

## 6. Acknowledgments.

Acknowledgment is due to the management and employees of the following factories which participated in the investigation—the Carlisle River Dairy Co. Ltd., the Geelong Co-op. Association Ltd., Wallace, Millbrook, and Buninyong Butter Co. Ltd., Holdensen and Nielson Pty. Ltd., Numurkah, and the Colac Dairy Co. Ltd. Thanks are also due to officers of the Dairy Division of the Victorian Department of Agriculture who assisted in the planning and management of the investigation and to officers of the Department of Commerce and Agriculture who also assisted in this respect and graded the experimental butters.

Dr. W. J. Wiley, Officer-in-Charge of the C.S.I.R. Dairy Research Section, made many of the preliminary arrangements for the conduct of the experiment and assisted with helpful advice and suggestions. The author is indebted also to Miss J. Matthews who carried out the bacteriological examinations and to Mr. R. Wilkinson who assisted in the analytical work.

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# The Catalytic Dehydration of the Amyl Alcohols of Fusel Oil with a Kaolin Catalyst of High Activity.

*By K. E. Murray, B.Sc.(Hons.)**

*Summary.*

A short study has been made of the dehydration of an amyl alcohol fraction of fusel oil, using a kaolin catalyst of local origin. This amyl alcohol fraction (boiling range 128–132°C.) was mainly 3–methyl–1–butanol, with 15·4 per cent. of laevo 2–methyl–1–butanol.

The catalyst possessed high activity. Even at the highest flow rate, conversion to hydrocarbons was practically complete, and an analysis of the product (3–methyl–1–butene, 6 per cent.; 2–methyl–1–butene, 23 per cent.; and 2–methyl–2–butene, 64 per cent.) showed that isomerization to the equilibrium value for the methyl butenes had taken place.

An X-ray examination of the catalyst has shown it to consist mainly of kaolinite, with small amounts of montmorillonite and mica.

## 1. Introduction.

In seeking uses for the fusel oil which would have resulted from the operation of the government-owned alcohol grain distilleries, attention has been given to the production from it, and from phenol, of p–tert–amyl phenol, which is used in the preparation of oil-soluble phenolic resins. Phenol and isoamyl alcohol give mixtures of several amyl phenols by direct condensation, but when isoamyl alcohol is first dehydrated, and the amylene (chiefly 2–methyl–2–butene) condensed with phenol in the presence of an acid catalyst, p–tert–amyl phenol is obtained as the only product. The dehydration of a mixture of 3–methyl–1–butanol and 2–methyl–1–butanol, such as occurs in fusel oil, might be expected from the structural formulae to give 3–methyl–1–butene and 2–methyl–1–butene as products, but isomerization often occurs, depending on the catalyst, and 2–methyl–2–butene is obtained as the chief product. Ewell and Hardy (1) have established that, over catalysts, the pure methyl butenes at 358°C. isomerize to an equilibrium mixture as follows:—3–methyl–1–butene, 3·6 per cent.; 2–methyl–1–butene, 27·6 per cent.; 2–methyl–2–butene, 68·8 per cent. This indicates that at this temperature the percentage of 2–methyl–2–butene in the products of dehydration of the amyl alcohols of fusel oil cannot exceed the above equilibrium value.

Since 2–methyl–2–butene is the desired product of the dehydration, the purpose of this investigation was to find or prepare an active catalyst which would not only dehydrate the alcohol, but would also isomerize the amylenes to give a maximum proportion of 2–methyl–2–butene. This search was simplified by the fact that, during an investigation in this laboratory on the dehydration of ethanol to ethylene, a kaolin catalyst† of high activity had been discovered and used on laboratory and pilot plant scale. Its activity was therefore determined in respect to both of the above requirements.

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* An officer of the Division of Industrial Chemistry.

† This catalyst has also been used extensively in the laboratory for the preparation of other olefines, viz., propylene from n–propanol and isopropanol, n–pentenes from n–amyl alcohol, tetra–methyl ethylene from pinacolyl alcohol, and cyclohexene from cyclohexanol.

## 2. Experimental.

An Australian fusel oil of "brine-washed" grade was fractionated through a glass column $\frac{7}{8}$ in. internal diameter, and packed for 42 in. of its length with $\frac{1}{8}$ in. diameter single-turn glass helices. Eight litres of the fraction boiling at 128–132° C., amounting to 60 per cent. of the charge, were prepared: this contained 15·4 per cent. of 2–methyl–1–butanol, as calculated from the optical rotation.

The sample of kaolin catalyst was taken from a 5 cwt. lot mined near Gordon, Victoria*. It was almost pure white, and was prepared for use by coarsely crushing, separating the portion 4–8 mesh, and heating this for one hour at the reaction temperature. An X-ray analysis has shown the catalyst to be composed mainly of kaolinite, with small amounts of montmorillonite and mica.

The apparatus used for the dehydration is shown diagrammatically in Fig. 1. Amyl alcohol (boiling range 128–132° C.) contained in the constant head reservoir (A) was fed at a constant rate by a bellows pump (B) to the preheater (C), which consisted of a Pyrex tube 1·5 cm. in diameter, packed with Pyrex chips, electrically heated and lagged. The temperature of the preheated vapour was adjusted by a Sunvic Simmerstat (D). The reaction chamber (E) was a Pyrex tube 3 cm. diameter fitted with a central thermocouple well of 6 mm. tubing. The annular space was packed before each run to a depth of 30 cm. with 200 g. of the catalyst. A thermocouple was situated midway along the bed. The catalyst tube fitted closely into an electric tube furnace (F) constructed on a length of 45 cm. stainless steel tubing, its temperature being controlled by a controller (G) from a second thermocouple between the furnace and catalyst tubes. This arrangement largely eliminated "hunting" effects and gave good temperature control of the catalyst bed.

The products of the reaction passed through a water condenser to a coil and a receiver immersed in an alcohol-solid $CO_2$ bath (H) at 2–5° C. A trap (J) at –40° C. was included but all except a small amount of low boiling product was collected in the receiver in (H). The aqueous layer was separated by freezing it and pouring off the hydrocarbon layer.

The hydrocarbons obtained were analysed by fractional distillation in a vacuum jacketed column 11 mm. internal diameter, and filled for 276 cm. with 4 mm. diameter single-turn glass helices. The reflux head was a modification of that mentioned by Othmer and Ratcliffe (2), their single solenoid being replaced by two, one on each side of the tilting funnel and actuated by a variable electronic timing device. A charge of 500 ml. was used. High reflux ratios (50 : 1 to 20 : 1) were used except towards the end of the distillation when pure 2–methyl–2–butene distilled. The percentages of 3–methyl–1–butene (b.pt. 20·1°C.), 2–methyl–1–butene (b.pt. 31·0°C.), and 2–methyl–2–butene (b.pt. 38·6° C.) were estimated graphically by plotting temperature against volume of distillate.

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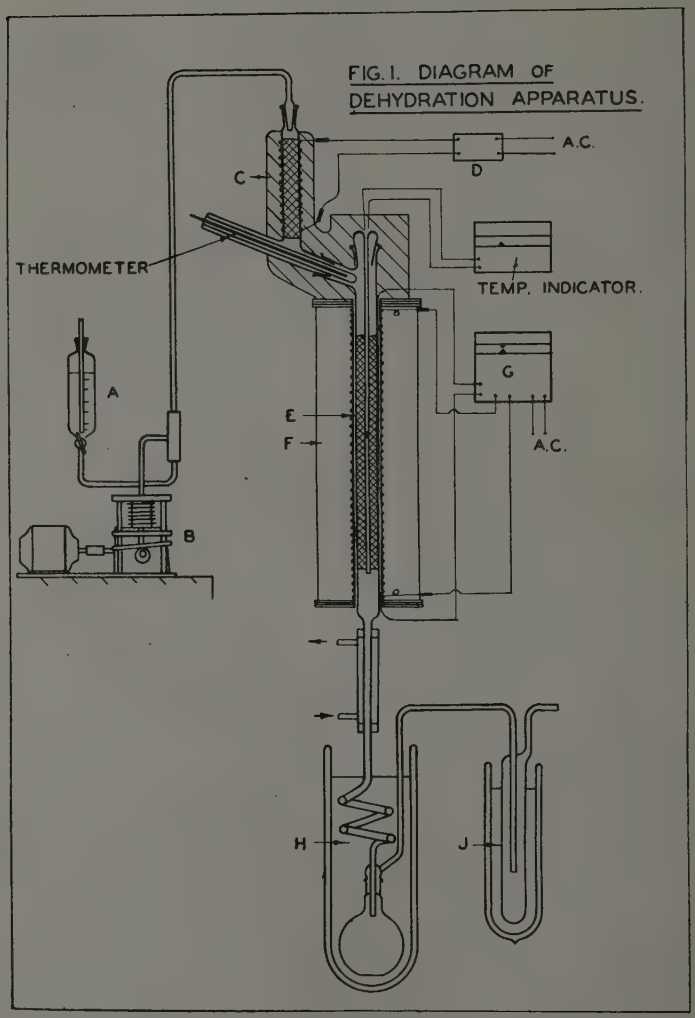
* Supplied by the Victoria Tile Co., Melbourne.




### 3. Results and Discussion.

Similar results were obtained from two runs made at catalyst temperatures of 442 ± 5°C. and 345 ± 5° C., at flow rates of 88 ml./hr. and 81 ml./hr. respectively. In each run the conversion to hydrocarbons was almost complete and the product contained 2–methyl–2–butene as the major constituent. The details of these runs are summarized in Table 1.

Runs were made at a catalyst temperature of 350 ± 5° C. to study the effect of increasing feed rates on the conversion to hydrocarbons and the degree of isomerization of amylenes during the dehydration. The feed rate was increased over five runs from 122 ml./hr. (Run 4) to 400 ml./hr. (Run 8). The flow rate was not increased further owing to the difficulty in supplying heat to the reaction at the high flow rate. In all these runs the conversion to hydrocarbons was greater than 97 per cent. The analysis of the product from Run 8 is shown in Table 1. It is seen that even at the high feed rate of Run 8 isomerization equilibrium has been reached. This result is sufficient to show that this kaolin catalyst possesses high activity for the dehydration of the amyl alcohols of fusel oil to a product consisting largely of 2-methyl-2-butene. This is supported by what little data is available in the literature on the activity of catalysts for this reaction (3).

TABLE 1.—SUMMARY OF RESULTS.

| Run No. | 1. | 2. | 8. |
|---|---|---|---|
| Catalyst | Kaolin 200 g. 4–8 mesh, 210 cc. | Kaolin 200 g. 4–8 mesh, 210 cc. | Kaolin 200 g. 4–8 mesh, 210 cc. |
| Temperature— | | | |
| Preheater | 260–270° C. | 260–270° C. | 350±10° C. |
| Centre catalyst | 442±5° C. | 345±5° C. | 350±5° C. |
| Outside catalyst | 470±10° C. | 370±5° C. | 395±5° C. |
| Alcohol input | 88 ml./hr. | 81 ml./hr. | 400 ml./hr. |
| Time of run | 7 hrs. 15 min. | 7 hrs. 15 min. | 2 hrs. 15 min. |
| Percentage conversion based on water produced | 98 | 97·5 | 97·4* |
| Product : Analysis (percentage by volume)— | | | |
| Low boiling fractions | 1 | 2 | 1 |
| 3-methyl-1-butene | 4 ± 0·5 | 3 ± 0·5 | 6 ± 0·5 |
| 2-methyl-1-butene | 24 ± 2 | 26 ± 2 | 23 ± 2 |
| 2-methyl-2-butene | 62 ± 2 | 61 ± 2 | 64 ± 2 |
| Higher boiling fractions | 4 | 3 | 3 |
| Loss and unaccounted for | 5† | 5† | 3 |
| Unchanged alcohol | None | None | 3% |

* Based on percentage alcohols recovered unchanged.
† These figures are high, possibly owing to high laboratory temperatures during these analyses.

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# The Chemical Composition of Natural and Synthetic Cryolite.

*By T. R. Scott, M.Sc.**

*Summary.*

The chemical composition of natural and synthetic cryolite is discussed and suggestions are advanced to account for the presence of combined water and the deficiency of sodium fluoride in the synthetic material.

## 1. Introduction.

In a recent publication (1), Tananaev and Lelchuk have stated that "as numerous samples of factory-made cryolite approximate to the formula 11NaF. $4AlF_3$, it seems obvious that the question of the chemical composition of cryolite is in need of revision." Analyses by Frere (2) and the writer leave no doubt that the formula for Greenland cryolite is $Na_3AlF_6$ (i.e. 3NaF. $AlF_3$), but it is equally certain that synthetic cryolite, precipitated from solutions containing aluminium, sodium, and fluorine, is deficient in sodium fluoride. Of the various explanations which have been advanced to account for this difference, several are not in accord with experimental evidence obtained by the writer and the present paper therefore represents an attempt to arrive at an explanation consistent with the available experimental evidence.

## 2. Sodium Fluoride Deficiency in Synthetic Cryolite.

Brosset (3) has described compounds, having the $NaF:AlF_3$ molar ratio of 2·57, which appear by X-ray powder photographs to possess lattice constants very little different from those of natural cryolite. In numerous analyses of manufactured cryolite, Yatlov (4) has found the ratio to vary between 2·4 and 2·8, although the constituents have been added in the correct stoichiometric proportions. The writer has prepared cryolite by many methods (5), but, in all samples analysed, the ratio has fallen within the range 2·73–2·96.

On the other hand, claims have been made that cryolite of the composition $Na_3AlF_6$ may be precipitated from solution. Tananaev and Talipov (6) claim to have prepared this compound by adding aluminium chloride to a large excess of sodium fluoride, the ratio "$NaF:AlF_3$" (sic) being not less than 8. On the assumption that $AlF_3$ in this ratio is a misprint for $AlCl_3$, an attempt was made to reproduce this result by adding sufficient aluminium chloride to a saturated solution of sodium fluoride to give a $NaF:AlCl_3$ ratio of 8·4 by weight. The precipitate was filtered with extreme difficulty and the wet solid analysed. (With a larger excess of sodium fluoride it was practically impossible to isolate the precipitate by filtration.) The ratio $NaF:AlF_3$ in the solid was found to be 2·91 after correcting for the sodium fluoride present in the wetting solution.

* An officer of the Division of Industrial Chemistry.

Tananaev and Lelchuk (1) have reported the formation of $Na_3AlF_6$ by mixing an excess of solid sodium fluoride with aluminium fluoride solution, but inspection of their results (q.v) has shown the claim to be untenable. The ratio obtained by the writer in a repetition of portion of their work was 2·70.

The large variations in the degree of sodium fluoride deficiency cannot be fully explained by variation in the concentration of reagents, though there is no doubt that the deficiency is much less with concentrated than with very dilute solutions. An important part must also be played by other factors, such as temperature, pH, nature of reaction, excess of one or more of the reagents, and rate and time of mixing.

### 3. Water of Constitution in Synthetic Cryolite.

All samples of synthetic cryolite analysed by the writer (Table 1) and by Frere (2) were found to contain water of constitution, requiring temperatures in excess of 600°C for its complete removal. The analyses in Table 1 were performed on well-washed samples, dried at 130°C, and experiments have shown that neither of these operations affect the $NaF:AlF_3$ ratio. Frere's analyses were on samples which apparently contained free sodium and aluminium fluorides, but, even under these circumstances, all but one of his hydrated samples was deficient in sodium fluoride.

It is consequently believed that water is invariably present in samples deficient in sodium fluoride, while it is highly probable that the presence of water can be regarded as an indication that the sample has a $NaF:AlF_3$ ratio lower than 3.

Table 1.—Composition of Synthetic Cryolite.

| Sample. | Water Content. | Molar Ratio. | |
|---|---|---|---|
| | | $H_2O : AlF_3$ | $NaF : AlF_3$ |
| | % | | |
| 1 .. .. | 1·88 | 0·21 | 2·73 |
| 2 .. .. | 1·20 | 0·14 | 2·87 |
| 3 .. .. | 1·50 | 0·17 | 2·93 |
| 4 .. .. | 1·31 | 0·15 | 2·96 |

The water content of synthetic cryolite shows a marked decrease with increase in the temperature of precipitation and is usually greater in samples having a large sodium fluoride deficiency. Considerable difficulty is experienced, however, in obtaining accurate quantitative correlation between water content and sodium fluoride deficiency, largely because of the formidable list of variables (given above) which may influence these two properties of synthetic cryolite. It is nevertheless evident that hypotheses which attempt to explain the low $NaF:AlF_3$ ratios in synthetic cryolite must also account for the presence of combined water.

### 4. Stability of Cryolite in the Presence of Water.

From a study of the system $NaF$–$AlF_3$–$H_2O$, Tananaev and Lelchuk concluded that two compounds, viz., $11NaF.4AlF_3$ and $3NaF.AlF_3$, were formed, the latter being unstable in the presence of water containing less than 1·39 per cent. sodium fluoride. Their results are reproduced in Table 2, in which the last row and column have been added by the writer.

TABLE 2.—SYSTEM $NaF$–$AlF_3$–$H_2O$.

| Weight. | | | | Molar Ratio NaF : $AlF_3$ in Solid. | |
|---|---|---|---|---|---|
| Solution. | | Solid. | | | |
| NaF. | $AlF_3$. | NaF. | $AlF_3$. | Uncorrected. | Corrected. |
| % | % | % | % | | |
| 0·039 | 0·303 | 11·16 | 8·25 | 2·71 | 2·78 |
| 0·038 | 0·149 | 8·59 | 6·25 | 2·75 | 2·80 |
| 0·037 | 0·071 | 15·20 | 11·20 | 2·72 | 2·72 |
| 0·118 | 0·059 | 13·70 | 10·21 | *2·68 | 2·68 |
| 0·178 | 0·0062 | 14·62 | 10·61 | 2·76 | 2·73 |
| 0·274 | 0·0021 | 15·55 | 11·63 | *2·67 | 2·64 |
| 0·88 | 0·0009 | 23·73 | 17·44 | 2·73 | 2·66 |
| 1·28 | 0·001 | 12·17 | 8·72 | 2·79 | 2·56 |
| 1·39 | Nil | 19·55 | 13·41 | 2·92 | 2·78 |
| 2·32 | Nil | 15·31 | 10·31 | 2·98 | 2·63 |
| 3·52 | Nil | 25·96 | 17·31 | 3·00 | 2·77 |
| 3·76 | Nil | 25·14 | 16·64 | 3·02 | 2·76 |
| 2·83 | Nil | 35·14 | 25·20 | 2·79 | 2·70 |

* Corrected for arithmetical error.

It appears that their values for the molar ratio $NaF:AlF_3$ have been based on analyses of the wet solids without correcting for the additional salts introduced by the wetting solution. The corrected values are shown in the last column and it is evident that the corrected molar ratio (2·70), in the presence of solutions containing less than 1·39 per cent. sodium fluoride, does not differ significantly from the value 2·72 obtained for the more concentrated solutions. There is consequently no evidence for the formation of the compound $Na_3AlF_6$ under the experimental conditions employed by Tananaev and Lelchuk. Their procedure was to stir varying quantities of sodium fluoride with saturated aluminium fluoride solution for 8–12 hours at $25·0 \pm 0·1°C$, after which the precipitate of cryolite was separated and analysed. The last line of Table 2 represents a faithful repetition of this procedure by the writer and it should be noted that the results so obtained are in very close accord with the corrected results of Tananaev and Lelchuk.

These authors also believe that "the compound corresponding to the formula $3NaF.AlF_3$ is decomposed by water and for that reason alone cannot exist in nature in the open state." In support of this claim, they state that three samples of Greenland cryolite analysed by them contained sodium fluoride and aluminium fluoride in the molar ratios 2·74, 2·75 and 2·72. These analyses are not in agreement with those of Frere (2) and the writer.

It is not surprising to find that natural cryolite differs from the compound obtained in the system $NaF–AlF_3–H_2O$ at 25°C, since the mineral was in all probability formed under totally different conditions. It might be expected, however, that it should be unstable in the presence of water and experiments devised to examine this possibility are described below.

If the reaction, $4Na_3AlF_6 \rightarrow NaF + 11NaF.4AlF_3$, occurs in the presence of water, it should be possible to detect the sodium fluoride in solution by titration with thorium nitrate. This possibility was tested by stirring three grams of finely-ground natural cryolite with 150 ml. of distilled water for five days at room temperature, but the fluorine content of the solution was not appreciably greater than that which would be expected if the cryolite were to dissolve congruently, with the solubility figure of 0·41 g. per litre at 25°C. (6). The experiment was repeated with exceedingly fine material which had been ball-milled with glass beads for ten hours, but again with unsatisfactory results. Difficulty was experienced in obtaining sharp end-points in the thorium nitrate titration, due to the presence of aluminium in solution, and small increases in the titre could not be detected with certainty.

As an alternative procedure, finely-ground cryolite was again stirred with water as described above, but the ball-milling with glass beads was omitted and stainless steel vessels and stirrer were used. The resulting solutions were analysed and the Na : Al ratio was found to be almost exactly 3·0.

From these results, it may be concluded that there is no evidence to show that the mineral cryolite is unstable in contact with water. This is in accord with the work of Tananaev and Talipov (6), who determined the solubility of sodium and potassium cryolite by evaporating solutions to dryness after equilibrium had been attained and weighing the residues. They assert that "analysis of the dry remainder(s) showed conformity with the formula $Me_3AlF_6$". In the case of potassium cryolite, however, this statement is at variance with that of Brosset (3), who claims that potassium cryolite is "transformed into $K_2AlF_5.H_2O$ . . . very rapidly in contact with water". This remarkable difference between the behaviour of sodium and potassium cryolite may conceivably be associated with the non-existence of sodium penta-fluoaluminate.

### 5. Suggested Explanations for the Sodium Fluoride Deficiency.

Sufficient evidence has been adduced to disprove the contention of Tananaev and Lelchuk (1), that the compound $Na_3AlF_6$ is incongruently soluble in water, and this explanation must therefore be discarded.

During the progressive neutralization of solutions of "fluoaluminic acid" ($H_3AlF_6$) with sodium carbonate, Yatlov (4) has found that sodium tetra-fluoaluminate ($NaAlF_4.H_2O$) is the compound first formed. He believes that this compound subsequently reacts with sodium fluoride to produce cryolite, having a $NaF : AlF_3$ ratio not greater than 2·8. This sodium fluoride deficiency in the precipitate is ascribed to "incomplete transformation (of the tetra-fluoaluminate) due to kinetic conditions." However, if simple combination with sodium

fluoride occurs, the cryolite produced should contain at least 7 per cent. (1 mole) of water. If, on the other hand, sodium fluoride replaces water in the compound $NaAlF_4.H_2O$, anhydrous cryolite should be obtained. Neither of these possibilities has been observed in practice. Moreover, the hypothesis does not appear to fit those reactions in which solutions of aluminium salts are added to excess sodium fluoride (p. 442).

It has been suggested by Brosset (3) that, in addition to $[AlF_6]^{3-}$ ions, other complexes such as $[Al(H_2O)F_5]^{2-}$ exist in solution, and partially take the place of $AlF_6$ octahedra in the crystal lattice of the precipitated cryolite. This modification can take place without difficulty, because of the similarity in the dimensions of coordinated fluorine ions and water molecules. The presence of coordinated water would explain why such relatively high temperatures are required to dehydrate the cryolite, and why considerable difficulty is experienced in avoiding losses of fluorine, as hydrogen fluoride, during dehydration. In this connexion, it is interesting to note that the compound $K_2AlF_5.H_2O$, also examined by Brosset, does not contain complexly-bound water, and is completely dehyrated at temperatures as low as 270°C. Portion of the water, in fact, is reversibly removed at temperatures below 135°C. This compound contains chains of $AlF_6$ octahedra, and is quite distinct from the cubic potassium cryolite $K_{2\cdot8}AlF_{5\cdot8}$, in which there is no sharing of fluorine ions in adjacent octahedra. The presence of 0·2 moles of water is invoked to enable the aluminium ions in this structure to retain their usual sixfold coordination.

This hypothesis has the advantage that it accounts for the water content and the sodium fluoride deficiency of synthetic cryolite simultaneously. Knowing the lattice constants for cryolite with a $NaF:AlF_3$ ratio of 2·57, Brosset has calculated the densities for a variety of possible compounds, with and without combined water, and has compared the figures obtained with the experimentally-determined density. He concludes that the most probable formula is $Na_{2\cdot57}AlF_{5\cdot57}(H_2O)_{0\cdot43}$, obtained by the substitution of water molecules for fluorine ions with displacement of an equivalent number of sodium ions. Several samples of synthetic cryolite analysed by the writer show agreement with this suggestion.

It must be stressed that this theory is based on the assumption that, in solutions containing fluorine and aluminium, a variety of complex ions, such as $[AlF_6]^{3-}$, $[AlF_5]^{2-}$, $[AlF_4]^{-}$, exist in equilibrium with each other. Brosset has shown this to be so in very dilute solutions and has demonstrated that the ions having a higher F:Al ratio increase in concentration at the expense of those of lower F:Al ratio with increasing fluorine ion concentration. Little is definitely known, however, of the relative concentrations of the various ions during the precipitation of synthetic cryolite from more concentrated solutions used for large-scale preparations. From Brosset's work, it might be expected that, at sufficiently high concentrations, $[AlF_6]^{3-}$ ions would predominate to such an extent that the cryolite would be substantially anhydrous and only imperceptibly deficient in sodium fluoride. This possibility was investigated by adding concentrated tri-sodium aluminate solution to a large excess of 35 per cent. hydrofluoric acid, but the precipitate of cryolite was nevertheless hydrated and deficient in sodium fluoride, though less so than material precipitated from dilute solutions.

In certain instances (samples 3 and 4, Table 1), the proportion of water is much greater than can be accounted for by substitution of $Al(H_2O)F_5$ for $AlF_6$ groups. Furthermore, complete analyses sometimes show insufficient fluorine in the compound to combine with all the cations as NaF and $AlF_3$, indicating that fluorine ions have been replaced in part by hydroxyl ions. The occurrence of this type of replacement explains why a direct proportion does not always exist between the experimentally-determined water content and sodium fluoride deficiency in synthetic cryolite. In certain samples precipitated from concentrated solutions, even the replacement of fluorine ions by hydroxyl ions as well as by water molecules is inadequate to account for the water content. In such cases, it appears that the excess water must be loosely held at interstitial positions in the lattice.

Despite its inherent assumptions and limitations, however, Brosset's explanation of the peculiarities of synthetic cryolite is more satisfactory than any other theory which has been advanced. In particular, it appears to explain why samples of synthetic cryolite with varying $NaF:AlF_3$ ratios are all apparently stable in contact with water or solutions containing fluorine ions. Once the water is complexly bound in $[Al(H_2O)F_5]$ octahedra, it can only be replaced by fluorine with extreme difficulty. Although in solutions of natural cryolite, reactions such as $[AlF_6]^{3-} \longrightarrow [AlF_5]^{2-} + F^-$ may well occur, the solubility is so small that only the surface layers of the solid cryolite are affected by interchange of $[AlF_6]^{3-}$ ions for $[Al(H_2O)F_5]^{2-}$ ions and any such change is thus not detectable by ordinary methods of analysis.

## 6. Conclusions.

Synthetic cryolite, precipitated from solutions containing sodium, aluminium and fluorine, contains $Al(H_2O)F_5$ groups replacing $AlF_6$ octahedra in the lattice. Such material is therefore hydrated and deficient in sodium fluoride. The extent of replacement by $Al(H_2O)F_5$ groups can be decreased by using highly concentrated solutions in the preparation of the cryolite, but a wide variety of other factors, such as temperature, nature of reaction used, and excess of one or other of the reagents, must also play an important part in determining the composition of the material. Fluorine ions may also be replaced by hydroxyl ions, while loosely-bound water may be held at interstitial positions in the lattice; the water content may therefore be only roughly related to the degree of sodium fluoride deficiency. There is no evidence to show that anhydrous cryolite can be precipitated from aqueous solutions; the mineral $Na_3AlF_6$ must therefore have been formed under quite different conditions, but it nevertheless appears to be stable in contact with water.

## 7. Acknowledgment.

The writer is indebted to Professor H. S. Summers, Department of Geology, University of Melbourne, for the provision of samples of high-grade Greenland cryolite.

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# Preparation of Titanium Powder.

*By K. R. Hanna, F.M.T.C.,* and H. W. Worner, M.Sc.**

*Summary.*

Several methods of preparing titanium were critically studied with a view to selecting one for producing titanium needed in compounding gettering mixtures. The method selected was a modification of one developed by Kroll and consisted in the reduction of titanium tetrachloride with magnesium at 800° to 950°C. The product of the modified method contained not less than 98 per cent. titanium and it proved satisfactory as a constituent of certain gettering mixtures.

## 1. Introduction.

The chief aim of the work was to establish quickly a method of preparing titanium powder needed in compounding mixtures for gettering electron tubes. It was necessary that the method should be—

(*a*) Capable of immediate application in Australia under wartime conditions.†

(*b*) Capable of producing titanium with a low content of impurities (such as hydrogen and carbon) which might render it useless in "gettering" electron tubes.

(*c*) Simple and inexpensive.

## 2. Selection of Method for Trial.

The methods used in previous attempts to prepare titanium are described very briefly in the Appendix. Methods No. 1, 2, and 4 were not practicable because of shortages in the supply of sodium and calcium at the time when the titanium was required. The iodide dissociation method (No. 5) would have to be applied in a very elaborate and expensive manner if the required rate of production were to be achieved. The electrolytic methods were avoided because of contradictory reports about them (cf. No. 6 in the Appendix).

The method consisting of the reduction of titanium tetrachloride with magnesium (Kroll's method; No. 4 in the Appendix) was selected as the most likely to fill the requirements stated in the introduction. Distilled titanium tetrachloride and magnesium with a satisfactory degree of purity were available in sufficient quantity and the equipment and technique appeared to be reasonably well established.

## 3. Modification of the Selected Method.

The equipment and procedure described by Kroll were capable of yielding a product of purity appreciably higher than that required in gettering electron tubes. It was therefore decided to try the method using cheaper, modified apparatus and a slightly simplified procedure.

It was thought that a low-carbon steel crucible could be used instead of the molybdenum-lined crucible employed by Kroll. Construction of the main part of the reduction vessel in nichrome was considered

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† The method described below has been demonstrated to a number of Australian companies. With one modification it has been adopted by Amalgamated Wireless Valve Co. Pty. Ltd., of Sydney. This company keeps the furnace evacuated until the magnesium has been melted, at which stage argon to a pressure of 20 cm. Hg is admitted. An increased yield of titanium is obtained.

unnecessary and a relatively cheap heat-resisting steel was selected for the purpose. Provision of a gettered inert gas atmosphere within the vessel appeared to be unnecessary and it was decided to attempt the reduction after simply evacuating practically all the air from the vessel.

The reduction unit employed by the authors is illustrated in Fig. 1 and the modified procedure tried was briefly as follows:—

(i) Remove all scale and dirt from the crucible and internal parts of the vessel.

(ii) Assemble the equipment, having first placed the magnesium (in massive lump form) in the crucible.

(iii) Using an oil pump, reduce the gas pressure in the vessel to about 1 mm. of mercury.

(iv) Heat the lower end of the vessel to 600°C., keeping the gas pressure down by pumping all the time.

(v) Cut off the pump and heat to 800°C.

(vi) Introduce the titanium tetrachloride at a controlled rate. The temperature rises to about 950°C.

(vii) After introduction of all the titanium tetrachloride, keep the unit hot for nearly an hour, then allow the whole reduction unit to cool to room temperature before letting air into the vessel.

(viii) Open vessel and extract the reaction products (titanium and magnesium chloride) with the aid of a chisel.

(ix) Break up large lumps of products. As the mixture of reaction products is brittle, it can be broken up in a mortar with a pestel.

(x) Digest product with a 2 per cent. hydrochloric acid solution until all the magnesium chloride and residual magnesium appear to have dissolved.

(xi) Filter and wash the titanium.

(xii) Grind in a wet condition in a steel ball mill for about sixteen hours.

(xiii) Digest the powdered product with a one to three hydrochloric acid solution until the acid solution turns violet indicating (according to Kroll) the more or less complete removal of titanium oxides from the product.

(xiv) Filter the powdered metal and wash, firstly with water and then with alcohol.

(xv) Dry in an air oven at 120°C.

(xvi) Screen the powdered metal.

(xvii) Store in evacuated glass tubes.

Some data for a typical reduction campaign are as follows:—

| | |
|---|---|
| Weight of titanium tetrachloride .. .. | 1,500 grams |
| Weight of magnesium .. .. .. | 380 grams |
| Rate of addition of titanium tetrachloride .. | 83 grams/min. (47 ml./min.) |
| Maximum temperature .. .. .. | 950°C. |
| Weight of titanium produced .. .. | 300 grams |
| Titanium content of product .. .. | 98·1 per cent. |
| Yield of titanium metal (assuming oxygen is major impurity with magnesium 0·3 per cent. and nitrogen as a minor impurity —cf. Discussion). .. .. .. | 78 per cent. |

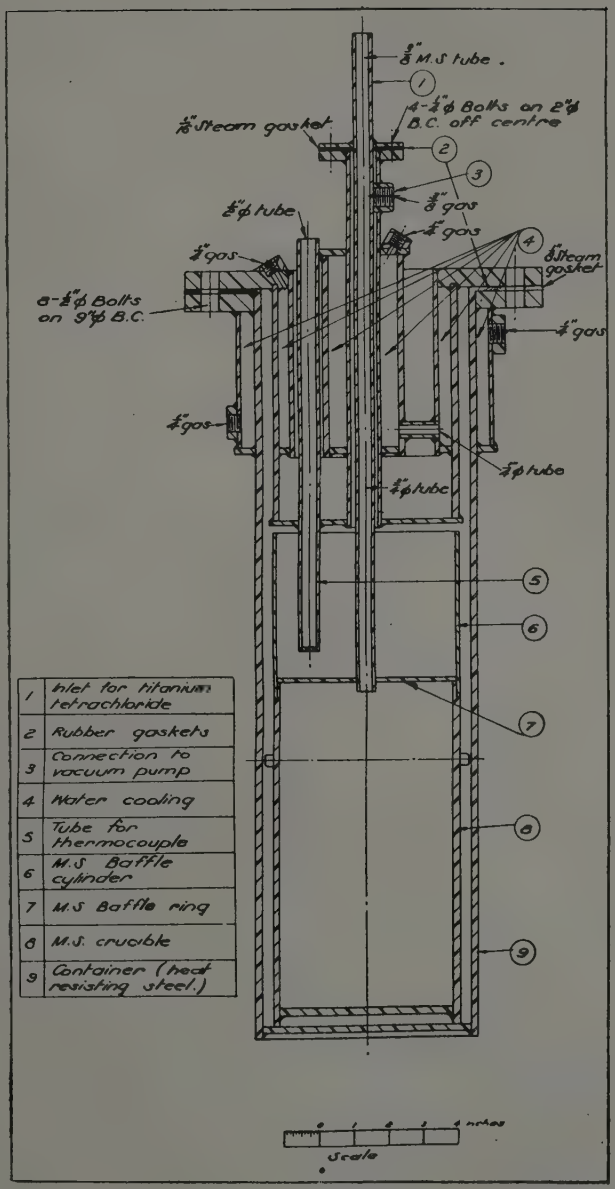


FIG. 1.—Sectional view of titanium reduction unit.

### 4. Discussion.

In order to achieve the most economical utilization of the reactants, it was found advisable to use the titanium tetrachloride and magnesium approximately in the proportion required by the equation—

$$TiCl_4 + 2Mg = Ti + 2MgCl_2$$

The yield of titanium was about 80 per cent. of that theoretically possible. A major part of the 20 per cent. loss was due to dissolution of titanium metal during the hydrochloric acid treatment for the removal of oxides from the pulverized titanium. The other major portion of the loss was in the form of solid lower chlorides of titanium, appreciable quantities of which were found in the reaction products. The presence of lower chlorides was probably due to lack of contact between the partially reduced titanium chlorides and small particles of magnesium which became entrapped in the main reaction products.

The proportion of titanium lost in the form of lower chlorides could be reduced by using more than the stoichiometric quantity of magnesium in each reduction campaign. However, an appreciable increase in the yield of titanium was possible only by using a very wasteful excess of magnesium.

Yields as high as those achieved by Kroll (approximately 95 per cent.) were not possible because in the authors' experiments it was not practicable to attain the high temperatures at which Kroll's reduction campaigns were completed. Kroll reported that temperatures over the boiling point of magnesium were reached at the end of his batch reduction operations, whereas the equipment used by the authors could not be safely taken over 950°C. In Kroll's procedure, the vaporization of all the magnesium at the completion of the operation would probably facilitate complete reduction of titanium chlorides.

It proved necessary to give special attention to the rate of adding titanium tetrachloride during the reduction process. When the rate was similar to that stated by Kroll (about 6 ml. per minute), the lower end of the inlet tube became blocked with reaction products before all the titanium tetrachloride had been introduced. To overcome this difficulty, the upper end of the inlet tube was fitted with a pressure gland holding a sliding plunger for use in dislodging accretions in the tube. The titanium tetrachloride was then introduced through a branch tube attached near the upper end of the inlet tube. Later it was found that blockage of the inlet tube could be prevented by adding the titanium tetrachloride at rates in the range 20 to 50 ml. per minute.

It was thought that the yield of titanium might be appreciably influenced by the rate of adding the titanium tetrachloride. However, it was found that varying the rate of addition in the range 5 ml. per minute to 60 ml. per minute had no measurable effect on the yield provided the crucible charge was kept above the melting point of magnesium for a total of about one hour.

The titanium content of the product was in the range 98 to 99 per cent. The main metallic impurity was magnesium, the content of which was approximately 0·3 per cent. A microscopical study of the titanium indicated that most of the magnesium was probably held as very fine particles entrapped within the titanium. The chief non-metallic impurity seemed to be oxygen in the form of titanium oxides.

most of which appeared to be present as surface films on the fine particles of titanium. Some finely dispersed inclusions which were thought to be titanium nitride, were detected during a microscopical examination of the titanium.

## 5. Acknowledgments.

We wish to express our gratitude to Mr. D. A. Cunningham who rendered considerable assistance in the early experimental work. Our thanks are also due to Miss R. I. Shoebridge who performed most of the chemical analyses. Miss M. Gardner, of the Munitions Supply Laboratores, Maribyrnong, kindly assisted by determining spectrographically the magnesium content of a sample of titanium.

## Appendix.

### Brief Description of Methods Proposed for the Preparation of Titanium.

1. Reduction of titanium tetrachloride with sodium in a bomb. The product is moderately pure and is in both massive and powdered form.

The method was first tried by Nilson and Petterson (1887) and was later developed by Hunter (1910). According to Kroll (1940), the method has been used by the Titanium Alloy Manufacturing Co., Niagara Falls.

2. Reduction of titanium tetrachloride with sodium in a salt bath covered with hydrogen at normal atmospheric pressure. The sodium and salt mixture are contained in a sealed iron vessel into which the titanium tetrachloride is carefully introduced. The product is spongy and contains some oxide.

The Deutsche Gold und Silber-scheideanstalt, Frankfurt am Main (1936) developed the method.

3. Reduction of titanium dioxide with re-distilled calcium at 1,000° to 1,200°C. in an atmosphere or argon at normal pressure. Calcium chloride and barium chloride are added to the reaction mixture to facilitate separation of the titanium from calcium oxide. The product contains about 98 per cent. titanium and contains some oxide. The method was used by Kroll (1934, 1937).

Reduction of titanium dioxide with calcium, calcium-sodium alloys and sodium was tried by Ruff and Brintzinger (1923) but the product of their attempt apparently contained no more than 83 per cent. titanium.

4. Reduction of titanium tetrachloride with magnesium at about 1,000°C. The reduction takes place in a molybdenum-lined steel crucible and the whole reaction vessel is filled with argon to prevent contamination of the product with oxygen or nitrogen. The titanium is produced in both massive and granular form. Kroll (1940), who worked out the method, claimed that it would yield a product containing 99·8 per cent. titanium.

5. Dissociation of titanium tetraiodide on a hot tungsten filament in a heated sealed vessel. This yields very pure titanium but the production rate is low. Details of the method have been published (Arkel and Boer, 1925; Arkel, 1934).

6. Electrolytic methods:—

(*a*) Electrolysis of molten rutile with carbon electrodes (Königsberger and Schilling, 1908). No statement of the purity of the product has been found but it seems certain that carbon and/or oxygen would be major impurities in the titanium.

(*b*) Electrolysis of a suspension of titanium dioxide in molten calcium chloride (Borchers and Huppertz, 1904; Huppertz, 1904). The titanium is said to form as a powder suspended in the electrolyte.

(*c*) Electrolysis of a solution of titanium dioxide in molten potassium chloride (List, 1923). The product is a compact cathodic deposit.

According to Sklyarenko *et al.* (1940), methods such as (*b*) and (*c*) above do not yield titanium but the lower oxides of titanium. They investigated the electrolysis of solutions of titanium dioxide in the following salts and salt mixtures: cryolite, calcium chloride, calcium chloride-sodium chloride mixture, and sodium chloride-sodium pyrophosphate mixture. In addition, they electrolysed a solution of potassium titanofluoride in a mixture of sodium and potassium chlorides.

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# A Critical Temperature Range in the Plastic Deformation of Plywood.

*By H. G. Higgins, B.Sc.(Hons.)*†

*Summary.*

An experiment is described which was designed to investigate the effect of temperature upon the residual deformation of plywood panels pressed for a fixed time under varying loads. It was found that, for oven-dry material, the load at which appreciable residual deformation took place declined rapidly with rising temperature from 120° to 160° C., and was very small above 160° C. The virtual disappearance of a yield value at or near this temperature represents a fundamental change in plastic behaviour, which, it is surmised, may be related to the physical properties of the lignin in the wood.

## I. Introduction.

Wood is a material of extreme complexity, both in the physical and chemical sense, and attempts to describe in rigorous terms its behaviour under stress are met with many more difficulties than in the case of homogeneous, isotropic substances of known composition and structure. The differences, for instance, between the elastic properties of wood in three directions—longitudinally, tangentially, and radially—have received detailed study. Similar differences in plastic behaviour must occur along these three axes, making extensive modifications necessary in the application to wood of conceptions of plasticity developed for isotropic substances.

The effect of temperature on plastic deformation is of practical importance in the fabrication of plywood by the hot press technique. For this reason plywood was chosen as the material for the present study, although its manner of construction adds to the inherent complexities of the wood substance itself.

The plastic behaviour of many materials may be described (Houwink, 1937, p. 11) by an equation of the form proposed by Herschel and Bulkley (1926)—

$$D = \frac{1}{\eta^*}(\tau - f)^n \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $D = \frac{d\gamma}{dt}$ ($\gamma$ = shear, $t$ = time)

$\tau$ = shearing stress

$f$ = yield value.

$n$ = a non-dimensional constant.

$\eta$ = viscosity ($\eta^*$ is a measure of the viscosity when $n \neq 1$, but will not have the dimensions of viscosity and can not be expressed in poises).

† An officer of the Division of Forest Products.

For a Newtonian liquid (the case of purely viscous flow), $f = 0$, and $n = 1$; so

$$D = \frac{\tau}{\eta} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2).$$

For a plastic solid (plastic flow) a yield value exists, but when it is exceeded the material behaves like a Newtonian liquid, and $n = 1$. Thus

$$D = \frac{\tau - f}{\eta} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3).$$

For quasi-viscous flow, no yield value exists, but $n \neq 1$, and the equation takes the form

$$D = \frac{\tau^n}{\eta^*} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4).$$

For quasi-plastic flow, equation (1) takes its full form.

Houwink (1937, pp. 17 *et seq.*) has pointed out that a study of the plasticity of a substance under a given set of conditions may best be made by methods which allow the results to be interpreted in terms of the physical constants $\eta$, $f$, and $n$. In this connexion $D-\tau$ curves are more suitable than the stress-strain curves used in the study of elastic deformation. An experimental method of investigating plasticity is always to be preferred if it allows the constants to be determined, although many attempts have been made to assess plasticity in other, less precise, terms. The prime object of the present investigation is to examine the effect of temperature upon one of the physical constants involved (yield value), and no attempt is made at this stage to examine the $D$-$\tau$ relations for the plastic deformation of wood under any given set of the other variables. Observations on plastic deformation at constant temperature are of a merely "conventional" nature.

## 2. Materials and Apparatus.

For the plasticity tests, plywood consisting of three plies was used. The veneer was rotary-cut hoop pine (*Araucaria cunninghamii* Ait.) of nominal thickness 1/16 in. and it consisted of closely matched material from the same log. It was bonded together with a phenol-formaldehyde film adhesive under a pressure of 50 lb./sq. in., for eight minutes at 145° C. Specimens 4 in. by 4 in. were cut from each panel, and for each series of tests, specimens were used from the same panel.

A modified "Carver" laboratory press was used in the experiment. The platens were heated electrically, and the temperature was controlled by means of a bimetallic strip thermostat inserted in each platen, and used in conjunction with a hot-wire vacuum switch. In some respects the apparatus resembled a Williams plastometer (Williams, 1924).

## 3. Preliminary Tests at Equilibrium Moisture Content.

The thickness of each specimen was measured with a micrometer gauge, each determination being the mean of eight measurements—one in each corner and one near the centre of each side. The moisture content of the specimens was in equilibrium with atmospheric conditions

in the laboratory at the beginning of the test. The specimens were subjected to a series of pressures ranging from 200 to 1,200 lb./sq. in. and at temperatures ranging from 120° to 200° C. Before applying the load each specimen was left in the press for two minutes with the platens closed. It was calculated (Norris, 1942, p. 124) that this should be sufficient time to bring the temperature of the whole specimen to within about a degree of the platen temperature. The load was then applied and maintained for five minutes, after which the specimen was removed from the press. The temperature of each platen was read at minute intervals from the time of insertion of the specimen. The thickness of the specimen was determined as before immediately after removal from the press. The results are shown in Table 1, in terms of residual deformation, which is the difference between the mean thickness before and after pressing.

TABLE 1.—RESIDUAL DEFORMATIONS (IN INCHES).

| Series of Tests. | Pressure (lb./sq.in.) | Temperature (° C.) | | | | |
|---|---|---|---|---|---|---|
| | | 120. | 140. | 160. | 180. | 200. |
| Preliminary Series (at equilibrium moisture content initially) | 200 | ·0027 | ·0022 | ·0019 | ·0018 | ·0019 |
| | 400 | ·0036 | ·0040 | ·0033 | ·0028 | ·0034 |
| | 600 | ·0068 | ·0043 | ·0079 | ·0048 | ·0079 |
| | 800 | ·0251 | ·0082 | ·0162 | ·0096 | ·0322 |
| | 1,000 | ·0438 | ·0218 | ·0188 | ·0212 | ·0497 |
| | 1,200 | ·0495 | ·0404 | ·0426 | ·0549 | ·0609 |
| Second Series (at 7 to 8 per cent. moisture content initially) | 200 | ·0026 | ·0011 | ·0023 | ·0029 | ·0053 |
| | 400 | ·0035 | ·0019 | ·0032 | ·0036 | ·0081 |
| | 600 | ·0057 | ·0050 | ·0050 | ·0077 | ·0160 |
| | 800 | ·0132 | ·0074 | ·0057 | ·0163 | ·0341 |
| | 1,000 | ·0272 | ·0163 | ·0224 | ·0291 | ·0648 |
| | 1,200 | ·0564 | ·0278 | ·0279 | ·0448 | ·0813 |
| Final Series (on oven-dry material) | 200 | ·0005 | ·0003 | ·0005 | ·0008 | ·0003 |
| | 400 | ·0002 | ·0005 | ·0011 | ·0022 | ·0018 |
| | 600 | ·0002 | ·0004 | ·0023 | ·0036 | ·0081 |
| | 800 | ·0005 | ·0011 | ·0019 | ·0056 | ·0235 |
| | 1,000 | ·0002 | ·0033 | ·0060 | ·0232 | ·0505 |
| | 1,200 | ·0043 | ·0069 | ·0260 | ·0414 | ·0639 |

Each figure represents the difference between the means of eight determinations of initial and final thickness.

### 4. Second Series of Tests.

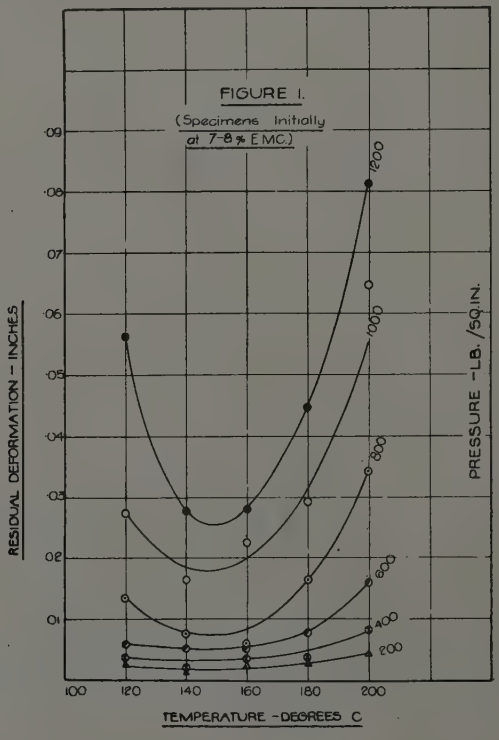
The preliminary series of observations were repeated using a somewhat more refined technique. It had been observed that the moisture content of the first series of specimens had varied considerably owing to changes in the weather, and in the second series all the observations were made when the moisture content of a control specimen kept with the rest was between 7 and 8 per cent., as determined by weighing, oven-drying, and re-weighing. In addition a simple device was used to ensure that the specimen was situated directly over the ram of the press. Apart from these modifications the same procedure was adopted as for the preliminary tests. Results are shown in Table 1 and graphically in Fig. 1.

### 5. Tests on Oven-Dry Material.

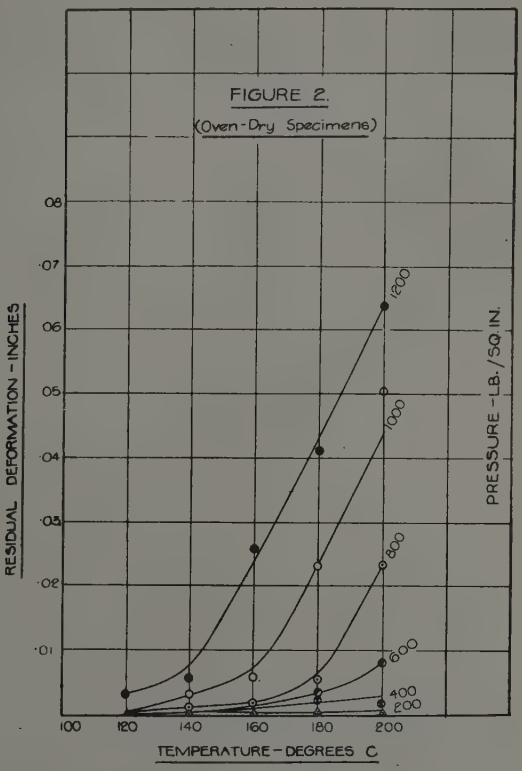
Examination of Fig. 1 revealed a minimum in the temperature-residual deformation curve for each load. To explain this the tentative hypothesis was adopted that the lower rate of drying at lower temperatures allowed the moisture to exert a plasticizing action on the wood for a longer time. For valid results therefore, it was evident that the moisture content had to be controlled for the duration of each test. The most convenient way of doing this was by using oven-dried specimens, and a new series of tests was carried out. The specimens were kept for two days in an oven maintained at 105° C. Directly after removal and before putting in the press, the thickness of each was measured; the rest of the procedure was similar to that adopted in the previous series of tests. The results are shown in Table 1 and are plotted in Figs. 2 and 3.

### 6. Effect of Moisture on Plasticity.

Reference to Figs. 1 and 2 reveals that even a small initial amount (7-8 per cent.) of water greatly increases the plastic flow. The minimum in the temperature-residual deformation curve is eliminated in Fig. 2, deformation rising throughout with increasing temperature.



It appears that the plasticizing action was exerted by the moisture in the form of steam, since the load was not applied until the temperature rose above the boiling point. At the higher temperatures most of the steam was driven off apparently before the load was applied. Seborg, Millett and Stamm (1944) have discussed the plasticizing action of moisture in connection with the manufacture of "Staypak" (heat-stabilized compressed wood).

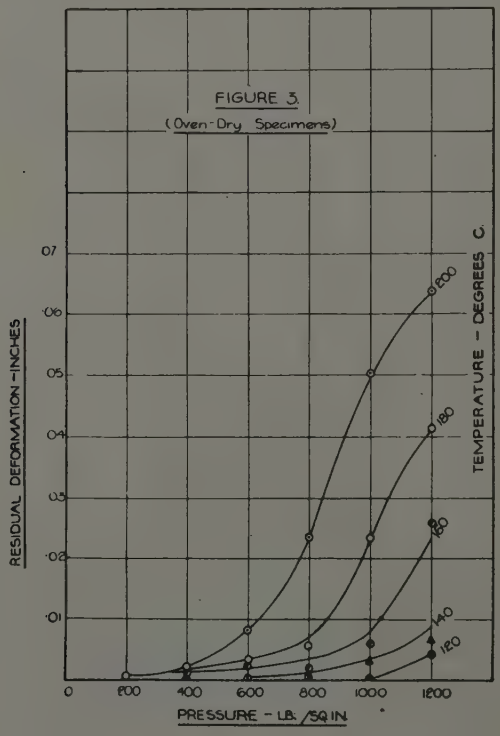



### 7. Effect of Temperature on Plasticity.

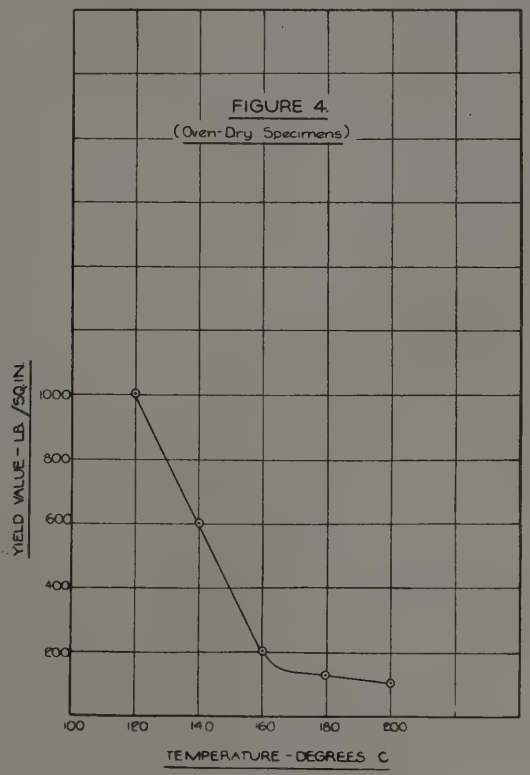
Fig. 2 shows the effect of temperature on the residual deformation of the plywood for various loads and it is evident from the differences in deformation at the two extremes of temperature that this range is highly critical. That this is particularly so at higher loads may be seen from Fig. 3, where the same data are plotted in the form of pressure-deformation curves, deformation rising sharply as the pressure increases.

If the yield value is taken as the point at which the pressure-residual deformation curves for various temperatures approach the load axis, a curve can be drawn showing the effect of temperature upon yield value. This takes the form shown in Fig. 4, the yield values being taken as the pressures corresponding to the points in Fig. 3 at which the smoothed curves intersected the +0·0005 in. abscissa, since very small residual deformations occurred even at low loads. It can be seen that with rising temperature the yield value declines rapidly from 120° to 160° C., above which it remains low. Temperatures in the vicinity of 160° C. may therefore be regarded as critical in the mode of plastic deformation, since the disappearance of yield value represents a fundamental change in the plastic behaviour, as has been pointed out earlier.

Yield values will almost certainly vary with the direction and rate of loading, as well as with the species and other factors. However, the critical temperature when the yield value vanishes or becomes very small may be largely independent of these factors, and may be dependent primarily on the nature and properties of the lignin which binds the cellulose fibres. (In this connection it is of interest to note that the



critical temperature range accords with the observed melting range of some dry extracted lignins.) Future work should be directed towards the elucidation of these problems, as well as towards the determination of $D$–$\tau$ relations.




## 8. Conclusion.

A temperature range in which yield value declined rapidly with rising temperature was found to exist in the plastic deformation under compression of oven-dry hoop pine plywood. This range embraces temperatures commonly used in the manufacture of plywood in the hot press. Below about 160° C. the wood behaved like a plastic or quasi-plastic solid, but at higher temperatures the yield value was very low, and the plastic behaviour of the wood could be better described as viscous or quasi-viscous flow. 160° C. therefore appeared to be a critical temperature in the plastic deformation of dry wood.

## 9. Acknowledgments.

Much of the experimental work in this investigation was done by Mr. P. McConchie and Miss J. Barrie.

## 10. References.

Herschel, W., and Bulkley, R. (1926).—*Koll. Z.* **39**: 291 (original not seen).

Houwink, R. (1937).—"Elasticity, Plasticity and Structure of Matter." (Cambridge University Press.)

Norris, C. B. (1942).—"Technique of Plywood." (Seattle: I. F. Laucks Inc.)

Seborg, R. M., Millett, M. A., and Stamm, A. J. (1944).—U.S. For. Prod. Lab., Madison, Wis., Rept. No. 1580.

Williams, I. (1924).—*Ind. Eng. Chem* **16**: 362.

# NOTES.

## The Chemical Engineering Section of the Division of Industrial Chemistry.

In 1937 the Federal Government appointed the Secondary Industries Testing and Research Committee to advise it concerning an extension of the activities of C.S.I.R. to provide assistance to Australia's secondary industries. One of the recommendations of this Committee was that a chemical laboratory should be established, and in April, 1940, effect was given to this recommendation by the formation of the Division of Industrial Chemistry. The terms of reference of the new Division were very wide; they were concerned chiefly with the improvement of technical efficiency in industry, the encouragement of new industries, a wider use of Australian raw materials in existing industries, and the utilization of industrial by-products. From the extensive field covered by this charter a selection was made based on the tentative policy that the problems chosen should be common to a whole industry or group of industries and that they should be as fundamental in character as the state of development of the particular industry permitted. It was realized that for certain industries, which had been somewhat slow in the adoption of scientific methods, the solution of a number of urgent problems of an *ad hoc* nature would have to precede the investigation of more fundamental problems. At an early stage, too, it was decided that in order to avoid a very large number of Sections the Division should be organized mainly on a subject basis with sections such as organic chemistry, biochemistry, and chemical physics, rather than on a project basis, with sections covering industries such as rubber, textiles, fellmongery, and building materials.

*Selection of Problems of Widest Application to Industry.*

During the war the course which the Division should follow in the selection of projects was clear; an abundance of pressing problems were already waiting which had to be dealt with by the Division either wholly or in collaboration with other institutions. Long-term work which was not urgent had, of necessity, to be postponed. Nevertheless, some broad principles were evolved upon which it seemed the development of the Division might still be based in times of peace. The selection of problems is relatively simple in some Sections of the Division; investigations of cement, on biochemical aspects of fellmongery, and of foundry sands, have been closely coordinated with the respective industries, either through a technical committee representative of the industry, or by intimate contact with most of the individual enterprises in the industry. There are, however, some sections in the Division where the scope is very broad and the selection of investigations which will be of the greatest benefit to industry can only be made by establishing and maintaining effective liaison and collaboration with a wide variety of industries.

The Chemical Engineering Section provides an example of this aspect of the Division's activities. The processes and techniques with which it deals, such as grinding, mixing, filtration, distillation, and

heat transfer are common to a wide variety of industries. The collaboration with so many industries, which is essential to place work on these processes in true industrial perspective, is inherently more difficult, and when reviewing the plans for developing the Chemical Engineering Section it was decided to explore the means by which this might be achieved.

As a first step it was decided to invite a number of technical men from industry, without regard to their industrial affiliations, to see something of the Section and to discuss the plans for its future development. It was impracticable to invite all those who might be interested but some 50 technical men, representative of those engaged in the teaching and practice of chemical engineering, attended conferences in Melbourne, in December, 1945, and in Sydney in May, 1946. The Sydney meeting was arranged under the auspices of the New South Wales branch of the Australian Chemical Institute.

*Present Work of the Section.*

At the conference held in Melbourne the visitors had an opportunity to inspect the equipment and pilot plant of the Section; in Sydney a set of photographs served to illustrate the types of work included in the Section's programme. These may be broadly defined as—

(1) Fundamental research in chemical engineering.

(2) The pilot plant development of chemical processes originating in other Sections of the Division.

(3) The application of relatively new techniques such as molecular distillation and dielectric heating.

(4) Improving the performance of existing process equipment.

(5) Investigations directed towards introducing and/or encouraging the local manufacture of materials of construction such as high-silicon cast iron, glass-lined equipment, and asbestos-filled resins.

(6) Short-term pilot trials for private firms when facilities are not available elsewhere.

Since its inception the Section has accumulated equipment for chemical engineering research, and has also built up a small staff of chemical engineers, technicians, and tradesmen.

The chief projects of the Section have been concerned with the production on a pilot scale of furfural from oat hulls and corn cobs; chromium compounds from Australian low-grade chromite; and rare earth compounds from the "black sand" deposits of the littoral areas of eastern Australia. While there is likely to be a steady flow of such projects arising from other Sections, it has been planned to give increasing attention to long-term research on certain problems of chemical engineering, of which heat transfer, factors affecting dropwise condensation, treatment of effluents, purification of gases by washing may be cited as examples. The plans embodying these projects were fully discussed at all the conferences and met with general approval.

*Some Present Needs of Industry.*

Additional problems of wide interest and some urgency to industry were brought forward. Those who attended the conferences were invited to do so, not because the Division was seeking projects for immediate investigation, but in order that these problems might be assigned priorities based on their incidence and urgency, and the facilities of the Chemical Engineering Section. Many expressed the view that both the facilities and the work of the Section were too little known and used and stressed the desirability of evolving some effective means of overcoming this. It was felt that much could be achieved by extending the present practice of disseminating information of interest to industry through the medium of trade circulars; through the interchange of staff between the Division and industry; and through more frequent reciprocal visits by both executive and technical men, with occasional demonstrations of the equipment and plant of the Section. It was suggested also that the publication of illustrated general articles descriptive of its facilities and methods of approach to chemical problems would help materially in this direction. When the work of the Section became better known it could be assumed that its attention would be drawn to other important problems, and that the resulting discussion would be of considerable value to the Section in coordinating its long range research with the needs of industry.

*Training of Chemical Engineers.*

On several occasions attention was drawn to the difficulties met with in designing plant for the large scale use of a process developed in the laboratory. Bridging this gap was costly, and many of these difficulties emphasized the dearth of suitably trained personnel. It was realized that the lack of practical plant knowledge, so evident among young graduates, was inevitable, since the lack of facilities at the teaching institutions precluded adequate attention being given to the claims of industrial chemistry. The chemical engineer, as distinct from the industrial chemist, should have an understanding of the principles underlying the operation of unit processes in order that he may apply them to the design of industrial processes and process equipment. The present facilities of the teaching institutions are inadequate, and it was strongly emphasized that the Division would fulfil a very important service to industry if it could afford students intending to become chemical engineers an opportunity to supplement their present training by spending a few months in the Chemical Engineering Section, to become familiar with process equipment and the approach to chemical engineering problems. Others might come to the Section for post-graduate training.

*Advisory Service to Industry.*

It was hoped that the Division would be able to provide advice to industry on unit processes, on the choice of appropriate equipment for specific purposes, and on the technique of running pilot plants, and that opportunities might be given for technical men to observe the operation of specialized equipment which the Section sets up from time to time. The importance of good instrumentation in the efficient running of chemical plants is widely recognized, and it was suggested that advice on the selection of the most suitable instruments would be very welcome.

It was considered, too, that advice on the selection of suitable materials of construction for specific purposes might be of considerable value to industry, particularly with regard to new developments.

Several speakers stressed the advantage to industry of interchange of staff, a practice which the Division, from past experience, has every reason to regard as mutually beneficial. The advantages of sending officers abroad for experience was also emphasized. It was felt that C.S.I.R. should identify itself closely with trade associations, encouraging their formation and stimulating their development by the closest co-operation in all technical matters, and by undertaking fundamental work on problems of general concern which were beyond the resources of these Associations.

*Sponsored Research.*

Some regret was expressed that in Australia there was no organization which could provide assistance to manufacturing concerns for the solution of problems of specific interest to themselves, for which they would meet at least the major portion of the cost. Such organizations do exist in certain other countries, and flourish as a result of the very useful function they perform in the interests of wide sections of industry. It was realized that the size of chemical industry in Australia might make it difficult to justify and maintain such an organization, and the question was raised as to whether the Division would be prepared to undertake investigations for individual firms under some mutually satisfactory financial arrangement. It was explained that although the Division has received financial support from several trade associations, its policy has been to avoid privately-sponsored investigations. There is, however, no bar to work which would benefit only one firm at present, provided that it is not in conflict with existing consulting practices and the firm is agreeable to the publication of the results. In general, requests of this kind have been favourably considered only if they required special skills or equipment not elsewhere available, or if the work provided valuable experience for the Division's officers. It has been regarded as the responsibility of industrial firms to recruit and maintain adequate technical staffs, which are a prerequisite for the introduction of scientific methods.

The policy of the Division with regard to testing was raised, and it was agreed that routine testing should not be undertaken. However, it was felt that where the Division possessed special facilities or skills, it should use these in developing methods of testing and occasionally in testing of specific materials. Thus, since the Division possesses the only electron miscroscope of its kind in Australia, it is prepared to use it on both basic research and *ad hoc* work for the benefit of industry. Other exceptions occur from time to time when equipment is already set up, and its use for pilot or type trials may avoid expensive duplication by industry. These instances do not fall into the category of routine testing, for which certain other laboratories possessing appropriate facilities and skills already exist.

*Publication of Results.*

A discussion on publication indicated complete support for the Council's policy of insisting on publication of its work irrespective of whether outside interests contribute financially towards the investiga-

tions. This policy excludes any suggestion of sectional interests deriving special benefits, and the Council's work is freely available to all sections of the community.

*Implementing Suggestions.*

In considering the suggestions arising from these discussions, with a view to implementing those which are feasible having regard to staff and facilities, it was gratifying to find that most of them represented extensions of the present activities of the Division. The Section was urged vigorously to continue to build up a team, each member of which would be experienced in dealing with the problems associated with the commonly occurring unit processes, in the application of the various materials of construction, or in the use of measuring, recording, and controlling instruments, and who would also conduct research in his chosen subject. While assistance in the training of students cannot be accepted as a permanent function of the Division, it is proposed to continue as a temporary expedient to provide opportunities for a limited number of chemical engineering students to gain practical experience in the Section. It is also proposed to extend the interchange of staff with industry, and to provide additional facilities for guest workers. In addition, a number of the Division's officers have been sent abroad to gain further experience.

The Division was urged to make closer contact with industry. Already effective liaison has been established with trade associations connected with the fellmongering, cement, towns gas, leather, and foundry industries, and it is proposed to appoint a liaison officer to establish more effective liaison with other industries in which chemical engineering is of major importance.

These Conferences contributed much to the mutual understanding between officers of the Division and the technical men of industry, but perhaps their most encouraging features were the evident desire on the part of industry to collaborate with the Division and the general agreement that the Division's plans were along the lines most likely to afford assistance to our secondary industries.

## Catalogue of Scientific and Technical Periodicals. New Edition.

The following list is supplementary to those published in the February and May, 1946, issues. Libraries possessing items with which they are not credited are requested to forward missing entries, showing holdings, to Mr. E. R. Pitt, care of C.S.I.R. Information Service, 425 St. Kilda-road, Melbourne, S.C.2, for inclusion in the Catalogue. As full information as possible is given, and bibliographical accuracy cannot be guaranteed.

NEW SCIENTIFIC AND TECHNICAL PERIODICALS.

Accelerator (American chemical society. *Indiana section*). Indianapolis, *Ind. monthly.*

Aero review. Penn Yan, *N.Y. monthly.* Monthly digest of world flight.

Agricultural engineering record (National institute of agricultural engineering). Askham Bryan, *York. quarterly.* (V. CSIR)

Agricultural institute review (Agricultural institute of Canada). V.1, no. 1 = Sept., 1945. *bi-monthly.* $2.00. Successor to C.S.T.A. Review. (V.CSIR:HO)

Air power league, *N.Y.* Bulletin. V.1, no. 1 = Aug., 1945.

Akademiya nauk. *Seriya biologicheskaya.* Izvestiya. Moscow. *irregular.*

Alcohol hygiene (National committee on alcohol hygiene, inc.). Baltimore, *Md. irregular.*

Allgemeine Textil-Zeitschrift. Poessneck, *Germany. monthly.* Supersedes Spinner & Weber.

Aluminum bulletin (Aluminum association). New York. *quarterly.*

American helicopter. New York. *monthly.*

Aminco laboratory news (American instrument company). Silver Springs, *Md. monthly.* Devoted to the application of scientific instruments to modern laboratory technique.

Annales de radioélectricité (Compagnies françaises associées de T.S.F.). Paris. *monthly.*

Army & navy bulletin. Washington, *D.C. weekly.*

Arquitectura portuguesa. Lisbon. *monthly.*

Atom. Denver, *Colo. quarterly.*

Atomic age. Sea Cliff, *N.Y. monthly.*

Atomic & gas turbine progress. New York. *monthly.*

Australia. *Works and housing, Dept. of.* Commonwealth experimental building station. Bulletin. No. 1 = 1946. (W.U)

Automovil. Caracas, *Venezuela. monthly.*

Bibliography of scientific & industrial reports (U.S. *Dept. of commerce. Office of the publication board.*) Washington, *D.C. weekly.* (V.CSIR)

Bituminous coal research (Bituminous coal research, inc.). Pittsburgh, *Pa. quarterly.*

Blood; the journal of hematology. New York. V.1 = 1946 (N.BMA; S.U)

Botanical review. Bronx, *N.Y. monthly.*

British millinery. London. *monthly.*

Bronze housekeeper (Bronze research services). Philadelphia, *Pa. monthly.*

Ceylon geographical society, *Colombo.* Bulletin. *irregular.*

Co-op power. Ithaca, *N.Y. monthly.* Deals with co-operative rural electricity.

Corrosion (National association of corrosion engineers). Houston, *Texas. quarterly.* V.1, no. 1 = Mar., 1945. (V.MSL)

Electronic news. Chicago, *Ill. monthly.*

Experientia. Basel, *Switzerland. monthly.* Monthly journal of pure and applied science.

Farm quarterly. Cincinnati, *Ohio.*

Flight plan (National aeronautic assoc.). Washington, *D.C. monthly.*

Food freezing. New York. *monthly.*

Gazeta dos caminhos de ferro. Lisbon. *semi-monthly.*

Geographica Helvetica. Zürich, *Switzerland. monthly.*

Gita (Grémio dos industriais de transportes em automóveis). Lisbon. *monthly.*

Hardware consultant & contractor. New York. *monthly.*

Health horizon (National association for the prevention of tuberculosis). London. V.1 = 1946. (S.U.)

Industrial plastics. Cleveland, *Ohio.* V.1, no. 1 = June, 1945. $2.50. *monthly.* (controlled circulation)

Ingeniería naval (Asociación de ingenieros navales). Madrid. *monthly.*

Intermédiaire des recherches mathématiques. Paris. 10 issues per year.

Inter-society council for textile research. News release. New York. *irregular.*

Journal of frequency modulation. New York. *monthly.*

Journal of polymer research. New York. V.1, no. 1 = Jan., 1946. $8.50. *bi-monthly.* (V.CSIR)

Journal of the history of medicine & allied sciences. New York. V.1 = 1946. *quarterly.* (S.U)

Material movement; the magazine of co-ordinated material handling. Pittsburgh, *Pa.* V.1, no. 5 = Nov., 1945. *monthly.*

Metal worker (Metal & machinery workers' ind.-union 440 *Cleveland branch*). Cleveland, *Ohio. monthly.*

Museum news (Toledo museum of art). No. 3 = 1946. (V.NMu)

National architect (National council of architectural boards). Detroit, *Mich. weekly.*

New York waterways (New York state waterways assoc.). *monthly.*

New Zealand. Dominion museum. Records in entomology. No. 1 = 1946. (N.U; W.U)

New Zealand. Dominion museum. Records in zoology. No. 1 = 1946. (W.U)

Occupational medicine. Chicago. V.1 = 1946. (N.PHD; N.SPH)

Optik. Weimar, *Germany. monthly.*

Papierfabrikant. Wochenblatt für Papierfabrikation. Berlin. *monthly.* Formed by union of Papier-fabrikant *and* Wochenblatt für Papier-fabrikation.

Peru. Instituto geológico del Perú. Lima. Boletín. *irregular.*

Plastics reporter. Boston, *Mass. monthly.*

Powder metallurgy bulletin. Yonkers, *N.Y. monthly.*

Prairie lumberman (Western retail lumbermen's association). Winnipeg. *monthly.*

Produits pharmaceutiques. Paris. V.1 = 1946 (S.U.)

Public works news. New York. *semi-monthly.*

Radio 45 (Société financière de radiodiffusion). Paris. *weekly.*

Radio maintenance. New York. V.1, no. 1 = July, 1945. *quarterly.* (Controlled free distribution.)

Radiopolis; revista mensual dedicada de la radiodifusión. México, *D.F. monthly.*

Refrigeration abstracts (American society of refrigerating engineers). V.1, no. 1 = June, 1946. $7. *quarterly.*

Retail grocer & provisioner. Toronto, *Canada. monthly.*

Revue suisse de l'imprimerie et des industries annexes. Lausanne, *Switzerland. monthly?*

Rocket-jet flying. New York. *quarterly.*

Science pictorial. New York. V.1, no. 1 = Sept., 1945. 25c. *monthly.*

Scientific forum. Los Angeles, *Cal. monthly.*

Sewage gas (Indiana. *Board of health. Division of environmental sanitation*). Indianapolis. *monthly.* A publication for sewage treatment plant operators.

Slide rule (Houston engineers' club). Houston, *Texas. monthly.*

Sociedad matematica mexicana. Mexico, *D.F.* Boletín. *quarterly.*

Sociedade geológica de Portugal. Boletim. Oporto. *irregular.*

Solar blast (Solar aircraft company). San Diego, *Cal. monthly.*

Southern laundry & cleaner. New Orleans, *La. monthly.*

Southern machinery & metals. Atlanta, *Ga.* V.1, no. 1 = Oct., 1945. $1.50. *monthly.*

Southern plastics magazine. Atlanta, *Ga.* V.1, no. 1 = Aug., 1945. $2.00.

Sweden. Sveriges meteorologiska och hydrologiska institut. Meddelanden. Serie B. Stockholm. *irregular.*

Té té; technisch tijdschrift voor de grafische industrie. Amsterdam-Zuid, *Netherlands. monthly.*

Tech book world, including Scien-tech index. Washington, *D.C. quarterly.* Listing technical books for practically every industry.

Tecnologia chimica. *Italy. monthly.*

Tekhnika molodezhi. Moscow. *monthly.*

Telephone worker (National federation of telephone workers). Washington, *D.C. monthly.*

Television digest & FM reports. Supplement. (Radio news bureau.) Washington, *D.C. irregular.*

Texas butane news (Texas butane dealers association). Austin, *Texas. monthly.*

Textil. Barcelona, *Spain. monthly.*

Textil ring. Apolda, *Germany. monthly.* Formed by union of Textil-industrie, Deutsche Wollen-Gewebe, *and* Deutsche Wirker-Zeitung.

Universal oil products company. News of science & industry in the U.S.S.R. Chicago. *bi-monthly?*

Vserossiiskoye mineralogicheskoye obshchestvo Zapiski. Moscow *quarterly.*

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## Recent Publications of the Council.

Since the last issue of this *Journal,* the following publications of the Council have been issued:—

*Bulletin* No. 197.—"The Analysis of the Hydrocarbon Gases by Fractional Distillation with Especial Reference to Cracked Tar Gases," by R. J. L. Martin, M.Sc.

A mixture of hydrocarbon gases was analysed by liquefaction and fractional distillation into the following fractions:—(1) Oxygen, carbon monoxide, hydrogen, methane, and nitrogen; (2*a*) ethylene; (2*b*) ethane; (3) propane, propene, and propadiene; (4) n-butane, isobutane, 1-butene, 2-butene, isobutene, and butadiene; (5) $C_5$ gases; (6) residues. Fraction 1 was analysed in the usual manner by gas absorption and combustion analyses. Fractions 3 and 4 were analysed by hydrogenation and absorption in acid mercuric nitrate solution. Isobutene was determined in fraction 4 by hydrochlorination and this method has been critically examined. The absorption of acetylene in potassium mercuri-iodide solution was examined, and this method was used for its estimation.

The low-temperature fractionating column and the constant-volume hydrogenation apparatus are described. A number of stopcock lubricants have been tested for use with this apparatus, and a mixture consisting of gelatine and an alkyd resin from tetraethylene glycol and citric acid has proved suitable.

*Bulletin No.* 198.—"Plant Responses to Molybdenum as a Fertilizer. 1. Molybdenum and Symbiotic Nitrogen Fixation," by A. J. Anderson, B.Sc. (Agric.), and Margaret P. Thomas, B.Sc. "2. Factors Affecting the Response of Plants to Molybdenum," by A. J. Anderson, B.Sc. (Agric.), and A. C. Oertel, M.Sc.

The first paper in this Bulletin shows that molybdenum is essential for symbiotic nitrogen fixation, and it would appear that the effects of molybdenum obtained with legumes, and those obtained by other workers with *Azotobacter,* were the result of the same fundamental effect of molybdenum in the function of nitrogen fixation. Experiments were also carried out on the effects of superphosphate on molybdenum-deficient soils. Unlike molybdenum, phosphate was directly concerned in host-plant metabolism. The lack of phosphate limited the development of the host plant, and this in turn limited the amount of nitrogen fixed. Under conditions of molybdenum deficiency, superphosphate increased the growth of subterranean clover, and thus increased the absolute amount of nitrogen in the leaves and decreased the percentage nitrogen. Where sufficient molybdenum was added, superphosphate also directly increased nitrogen fixation.

The second paper describes experiments conducted with two soils on which clovers respond to molybdenum. Vigorous growth of subterranean clover was obtained when phosphate and molybdenum were

applied together. The response to molybdenum increased as the level of phosphate approached the optimum. Applications of lime stimulated symbiotic nitrogen fixation by increasing the availability of molybdenum in the soil; no response to lime was obtained with grasses. Vanadium did not improve either the growth or the colour of legumes.

*Bulletin No.* 199.—"The Use of Mineral Dusts for the Control of Wheat Pests," by Frank Wilson.

This Bulletin describes a large-scale trial of the effectiveness of magnesite and dolomite dusts in preventing insect infestation when used as barriers on the wheat surface. Small-scale trials have been reported previously, but the work described was carried out in a Victorian bulk-wheat depot containing about 3½ million bushels of wheat. At the beginning of the trial the wheat had been in storage for more than a year, and the many infestations that had developed were being controlled by local fumigation.

At the dosages used commercially and in the trials, the dusts are of preventive value only, and their use must be supplemented by local surface fumigation of the infestations which develop despite the barrier. This dust-cum-fumigation method has been applied to some 16 million bushels of wheat in Victorian bulk-depots and has proved very satisfactory. The cost of the dust treatment, including labour costs, is about 0·03 pence per bushel. A surface dust-barrier considerably reduces the risk of serious damage from the explosion of wheat dust.

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## Forthcoming Publications of the Council.

At the present time, the following future publications of the Council are in the press:—

*Bulletin No.* 200.—"Preparation of Core Ingredients for Searchlight Carbons," by T. R. Scott, M.Sc., B.Ed.

*Bulletin No.* 201.—"Grazing Management: Continuous and Rotational Grazing by Merino Sheep. 1. Study of the Production of a Sown Pasture in the Australian Capital Territory under Three Systems of Grazing Management," by R. M. Moore, B.Sc.Agr., Nancy Barrie, B.Sc.Agr., and E. H. Kipps, B.Sc. *Appendix,* "The Measurement of Pasture Yield under Grazing," by G. A. McIntyre, B.Sc. "2. The Effect of Continuous and Rotational Grazing on the Infestation of Sheep with Internal Parasites," by H. McL. Gordon, B.V.Sc., and Helen Newton Turner. "3. A Note on Pasture Management," by J. Griffiths Davies, B.Sc., Ph.D.

*Bulletin No.* 202.—"The Strain Complex and Symptom Variability of Tomato Spotted Wilt Virus," by D. O. Norris, M.Sc. (Agric.).

*Bulletin No.* 203.—"Agar in Australia," by E. J. Ferguson Wood, B.A., M.Sc.

*Bulletin No.* 204.—"A Soil Survey of Part of Waterhouse Estate, County of Dorset, North-East Coast, Tasmania," by G. D. Hubble, B.Agr.Sc.

*Bulletin No.* 205.—"Studies on the Breeding Performance of Ewes," by R. B. Kelley, D.V.Sc.

*Bulletin No.* 206.—"Pedogenesis Following the Dissection of Lateritic Regions in Southern Australia," by C. G. Stephens, M.Sc.

*Bulletin No.* 207.—"The Fumigation of Wheat in Bag Stacks," by Frank Wilson and F. J. Gay, B.Sc., D.I.C.

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## PLATE 1.

Eradication of *Hydrocotyle tripartita* from Golf and Bowling Greens.
(See page 335.)

FIG. 1.—Typical *Hydrocotyle tripartita*, practice putting green, Royal Canberra Golf Club, before spraying.

FIG. 2.—Practice putting green, Royal Canberra Golf Club, 13 weeks after spraying with 0·1 per cent. 2,4-D.

## PLATE 2.

Eradication of *Hydrocotyle tripartita* from Golf and Bowling Greens.
(See page 335.)

FIG. 1.—Portion of typical *Hydrocotyle* colony, City Bowling Green, before spraying.

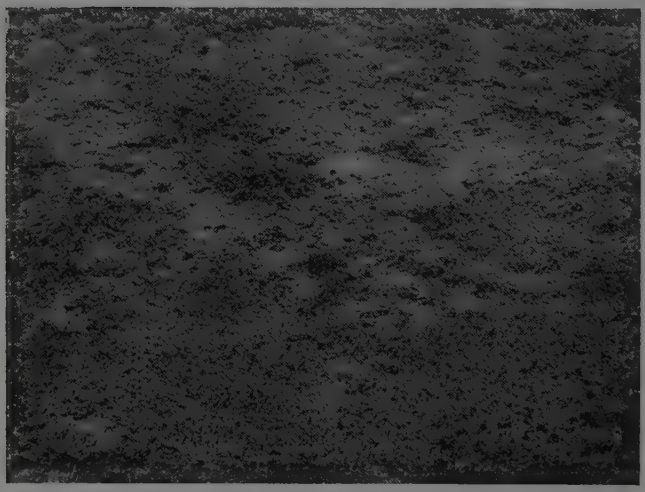

FIG. 2.—Former *Hydrocotyle* colony, City Bowling Green, after spraying with Methoxone. *Poa annua* covers an otherwise bare patch.

Fertilizers in Pasture Development on Peat Soils in the Lower South-East of South Australia. (See page 394.)

Showing poor development of clover on peat at Rendelsham treated with superphosphate only (above) compared with growth where trace elements including 7 lb. of copper sulphate per acre and 7 lb. of zinc sulphate per acre were applied in addition to superphosphate (below). Note the vigorous growth of Yorkshire fog in the absence of copper or zinc. (Experiment 1.)

**PLATE 4.**

Fertilizers in Pasture Development on Peat Soils in the Lower South-East of South Australia. (See page 394.)

FIG. 1.—Effect of 7 lb. of copper sulphate per acre (centre plot untreated) on the growth of lucerne on a coarse fibrous peat at Eight Mile Creek. (Experiment 6.)

FIG. 2.—Effect of 7 lb. of zinc sulphate per acre (right) on the growth of *Phalaris tuberosa* on Badenoch peat at Eight Mile Creek. (Experiment 7.)

**PLATE 5.**

Fusarium Wilt of Tomato in Australia. (See page 376.)

Bonny Best, Tatura Dwarf Globe, Pearson 29-17, and Pan America tomato plants one month after inoculation with *Fusarium bulbigenum* var. *lycopersici*.

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